# SHUTTLE RISK PROGRESSION BY FLIGHT

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# INTRODUCTION

- Understanding the early mission risk and progression of risk as a vehicle gains insights through flight is important
  - To the Shuttle Program to understand the impact of re-designs and operational changes on risk
  - To new programs to understand reliability growth and first flight risk
- Estimation of Shuttle Risk Progression by flight
  - Uses Shuttle Probabilistic Risk Assessment (SPRA) and current knowledge to calculate early vehicle risk
  - Shows impact of major Shuttle upgrades
  - Can be used to understand first flight risk for new programs

**Note: This is a significant update to previous versions dated prior to February 7th, mainly due to crediting crew escape on STS-1 and re-evaluation of Space Shuttle Main Engine (SSME)**

# SCOPE

- Estimating the Shuttle Risk for each flight is not feasible in the timeframe available, nor is it necessary because there may not be a noticeable difference between every flight
  - The following flights have been analyzed with the plan to fill in additional flights as necessary and as time permits
    - STS-1 – First Flight
    - STS-5 – Ejection Seats Disabled
    - STS-41B – Flight following STS-9 Auxiliary Power Unit (APU) fire
    - STS-51L – *Challenger*
    - STS-26 – Return to Flight after *Challenger*
    - STS-29 – Post STS-27 Solid Rocket Booster (SRB) nose cap Thermal Protection System (TPS) loss
    - STS-49 – Drag Chute introduced, Endeavour enters service
    - STS-77 – Block I and IA engines, New High Pressure Oxidizer Turbopump (HPOTP)
    - STS-86 – First flight of new External Tank (ET) foam application process
    - STS-89 – Earliest to combine Block IIA engines, New Large Throat Main Combustion Champer (LTMCC)
    - STS-103 – First flight of ET foam venting
    - STS-110 – First full Block II cluster, New High Pressure Fuel Turbopump (HPFTP)
    - STS-114 – Return to Flight after *Columbia*
    - STS-133 – Current Mission Risk

# MAJOR ASSUMPTIONS

- **General**
  - Modeling equivalent missions
    - International Space Station (ISS) mission with STS-119 mission duration and Micro Meteoroid and Orbital Debris (MMOD) (SPRA iteration 3.3 model)
    - So that risk differences are not about a particular mission objective
    - Easier to accomplish
    - Note that earlier missions although short in duration were dominated by risks which were independent of mission length (e.g. Reusable Solid Rocket Motor (RSRM), Ascent Debris)
      - Calculated STS-1 risk to be rounded to the same value with mission duration adjusted
  - No model logic changes only data changes
  - Crew error remains the same across the flights
  - MMOD risk is based upon STS-119
    - May be conservative for early flights since environment has been getting worse
    - May be non-conservative for later pre-Return To Flight (RTF) missions since Attitude TimeLine (ATL) adjustments were made post-RTF to reduce the MMOD risk
  - Crew Escape via ejection seats is modeled for STS-1
    - Ejection Seats are available for crew escape below ~80K feet which ~80 seconds on ascent and ~500 seconds on entry
    - Given a scenario that is assumed to be recoverable, ejection seats are given a 90% success rate (i.e. there is a 10% chance that either crewmember will not survive)
    - Scenarios which involve TPS failure (e.g. Ascent Debris, MMOD) are assumed not to be recoverable with ejection seats
    - Scenarios which occur on Orbit are assumed not to be recoverable with ejection seats.

# MAJOR ASSUMPTIONS (2)

- **Functional and Phenomenological Data**
  - All Bayesian updated data was reviewed and discounts taken for design changes were evaluated for when they were implemented and separate failure rates/probabilities were calculated based upon removing the discounts
    - For example Orbiter APU failure to run is automatically assigned a failure rate of 4.36E-3/hr if STS-1 is selected and 1.76E-3/hr if STS-133 is selected because of failures on STS-7 and STS-71 which had design changes implemented by STS-133
    - Unique data events such as tires and icicles forming during water dumps were evaluated separately and flight effectivities were assigned

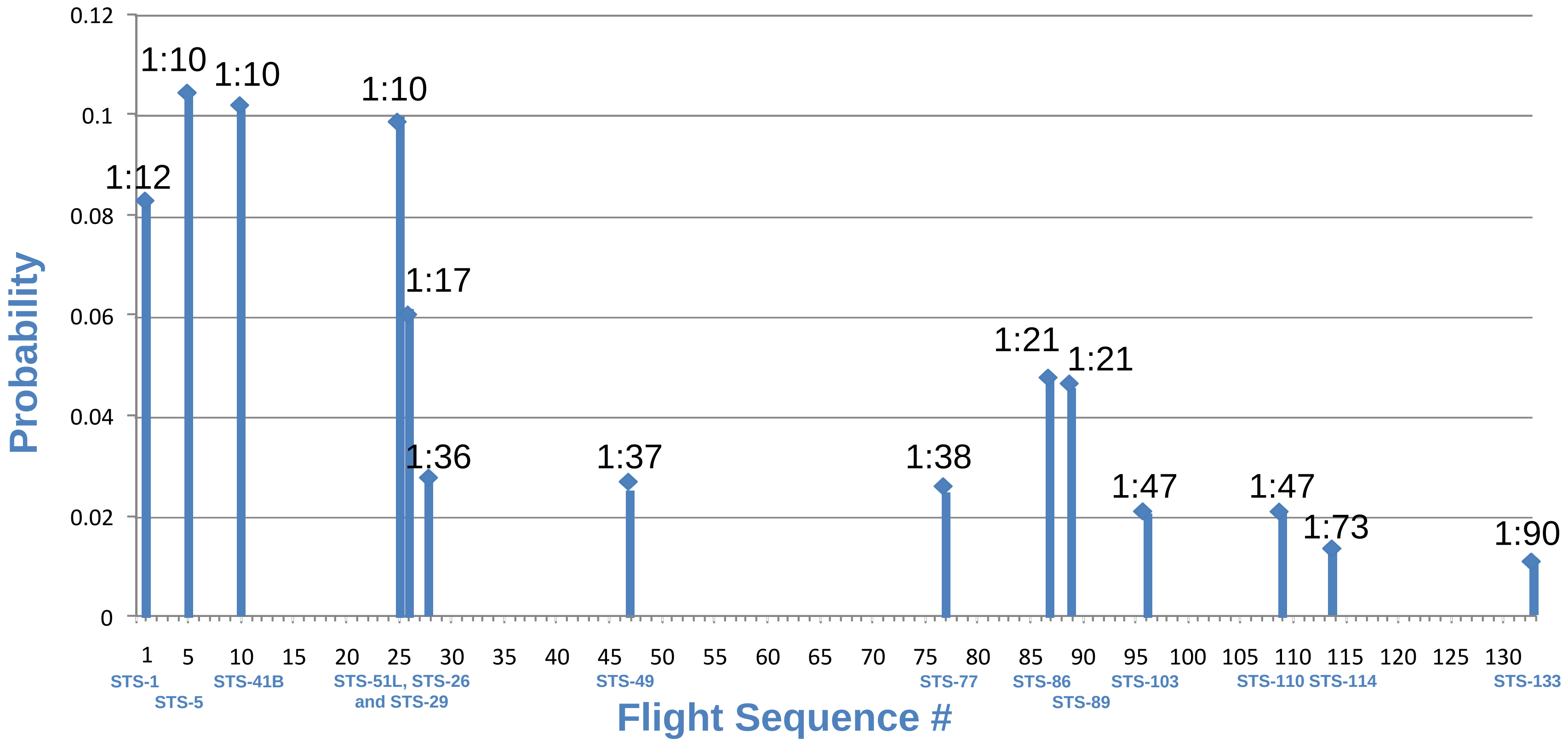
# MAJOR ASSUMPTIONS (3)

- **Ascent Debris Data**
  - Five possible groups of failure probabilities are used for the probability of critical Ascent Debris damage: STS-27 and prior, STS-28 through STS-85, STS-86 through STS-93, STS-103 through STS-114 and STS-121 and subs
    - This grouping was based upon significant changes in Orbiter damage which is used to assess ascent debris risk (additional information provided in backup)
  - Probability of Tile Damage using Ascent Debris Analysis Model (ADAM)
    - STS-27 and prior
      - Probability of critical tile damage based upon using frequency of damages on STS-6 through STS-27 input into ADAM, other inputs are based upon the Pre-RTF distributions documented in the iteration 3.2 notebook because dimensions and location of damages are unavailable
    - STS-28 through STS-85
      - Probability of critical tile damage based upon re-fitting ADAM input distributions based upon damages on STS-28 through STS-85
    - STS-86 through STS-93
      - Probability of critical tile damage based upon using frequency of damages on STS-86 through STS-93 input into ADAM, other inputs are based upon the Pre-RTF distributions documented in the iteration 3.2 notebook because dimensions and location of damages are unavailable for STS-87 which had the most significant damage
    - STS-103 through STS-114
      - Probability of critical tile damage based upon re-fitting ADAM input distributions based upon damages on STS-103 through STS-114
    - STS-121 and subs
      - Uses SPRA iteration 3.3 values which include return to flight improvements
  - Probability of Reinforced Carbon Carbon (RCC) damage
    - Probability of RCC damage STS-1 through STS-114 based upon using a Jeffreys prior Bayesian updated with 1 failure in 113 missions as the average risk from STS-1 through STS-114 and then calculating the risk at each point based upon the ratio of the tile risk at that point to the average tile risk (more details provided in backup)
      - Since the STS-27 and prior tile risk was ~2.2X the average the RCC risk is assume to be 2.2X the RCC risk average
    - Probability of RCC damage STS-121 and subs uses SPRA iteration 3.3 values which include return to flight improvements

# MAJOR ASSUMPTIONS (4)

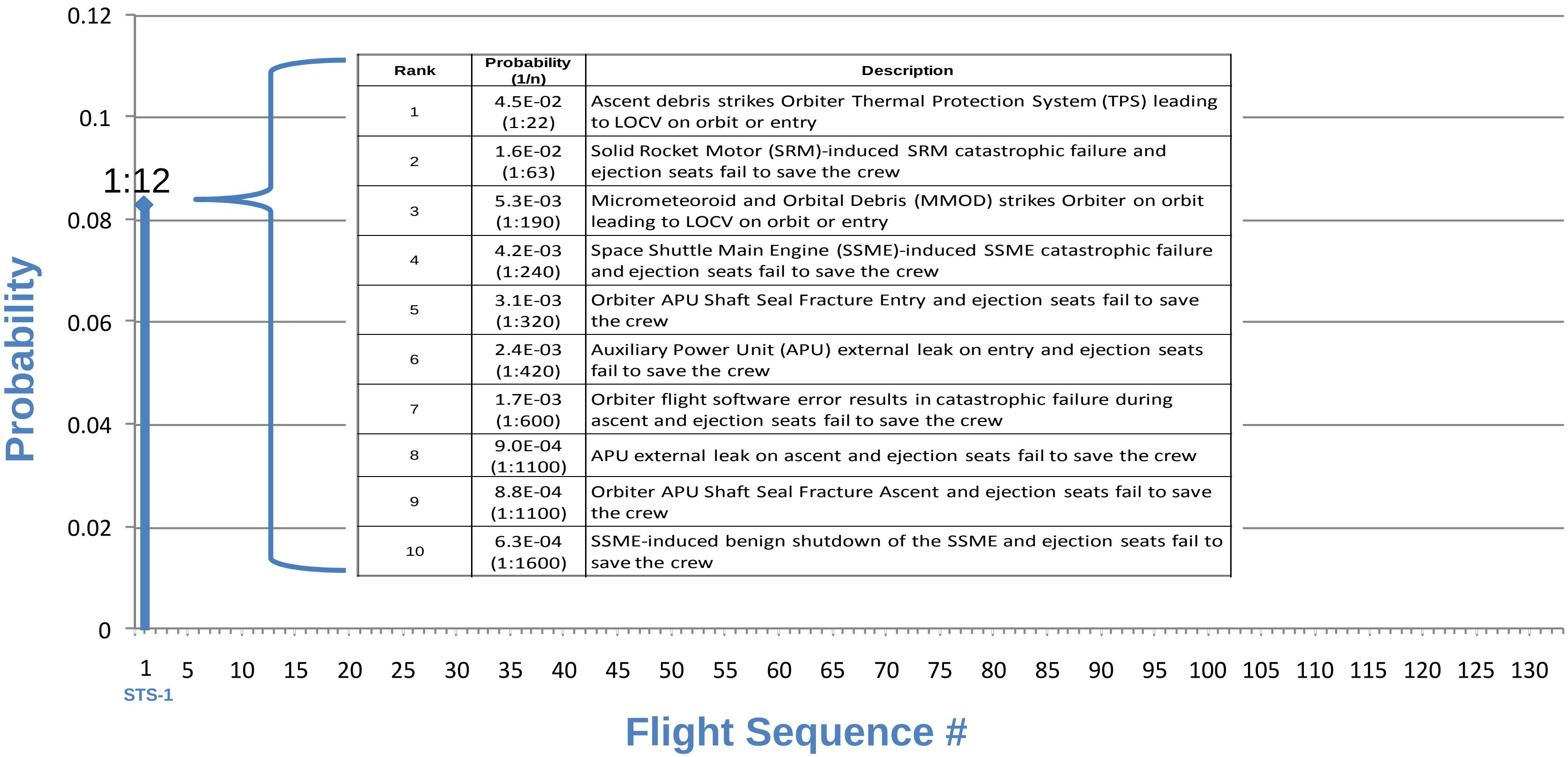
- **Space Shuttle Main Engine (SSME)**
  - Based upon evaluating the failures associated with a particular engine design, and each failure's root cause and its corrective actions. DAR life limits and additional inspection points have significant and "immediate" buy down in risk
  - All applicable failures are assumed to have been a risk present from the start of the SSME program.
  - Failure discounts due to differences in extended duration and ground testing power level are predominately associated with FMOF and FPL engines.
- **External Tank (ET)**
  - Based upon iteration 3.3 because in general this analysis does not model external tank changes, except as they impact Ascent Debris
  - Does not consider implications from STS-133 stringer cracks
- **Reusable Solid Rocket Motor (RSRM)**
  - Based upon 1 LOCV in 25 missions prior to *Challenger* and based upon iteration 3.3 for the remaining missions
    - The iteration 3.3 value is based upon expert elicitation, however discounting the failure based upon standard SPRA methodology would result in a similar value (~1:1300 vs. 1:1500)
- **Orbiter Flight Software**
  - Based upon the report "Primary Avionics Software System (PASS) Probabilistic Risk Assessment" which uses historical data from the Space Shuttle Program (SSP), to determine the LOC probability due to a failure in the PASS aboard the Shuttle
  - Although new software updates can introduce new errors, more errors are eliminated and the risk trends down

# RESULTS SUMMARY




- STS-1 estimate includes crew escape with ejection seats (Risk is 1:9 without ejection seats)
- STS-1 risk may have been higher due to unquantified risks
  - Underestimation of the SRB ignition overpressure which deformed FRCS oxidizer tank aft Z strut
  - Orbiter flight software risk is higher than estimated due to use of OI-1 estimate
  - TPS risk may be underestimated because ascent debris risk is based upon damages from STS-6 through STS-27 and on STS-1 there were numerous upper surface tile debonds
- Around STS-114 the Shuttle Program started actively using the Shuttle PRA in program decisions

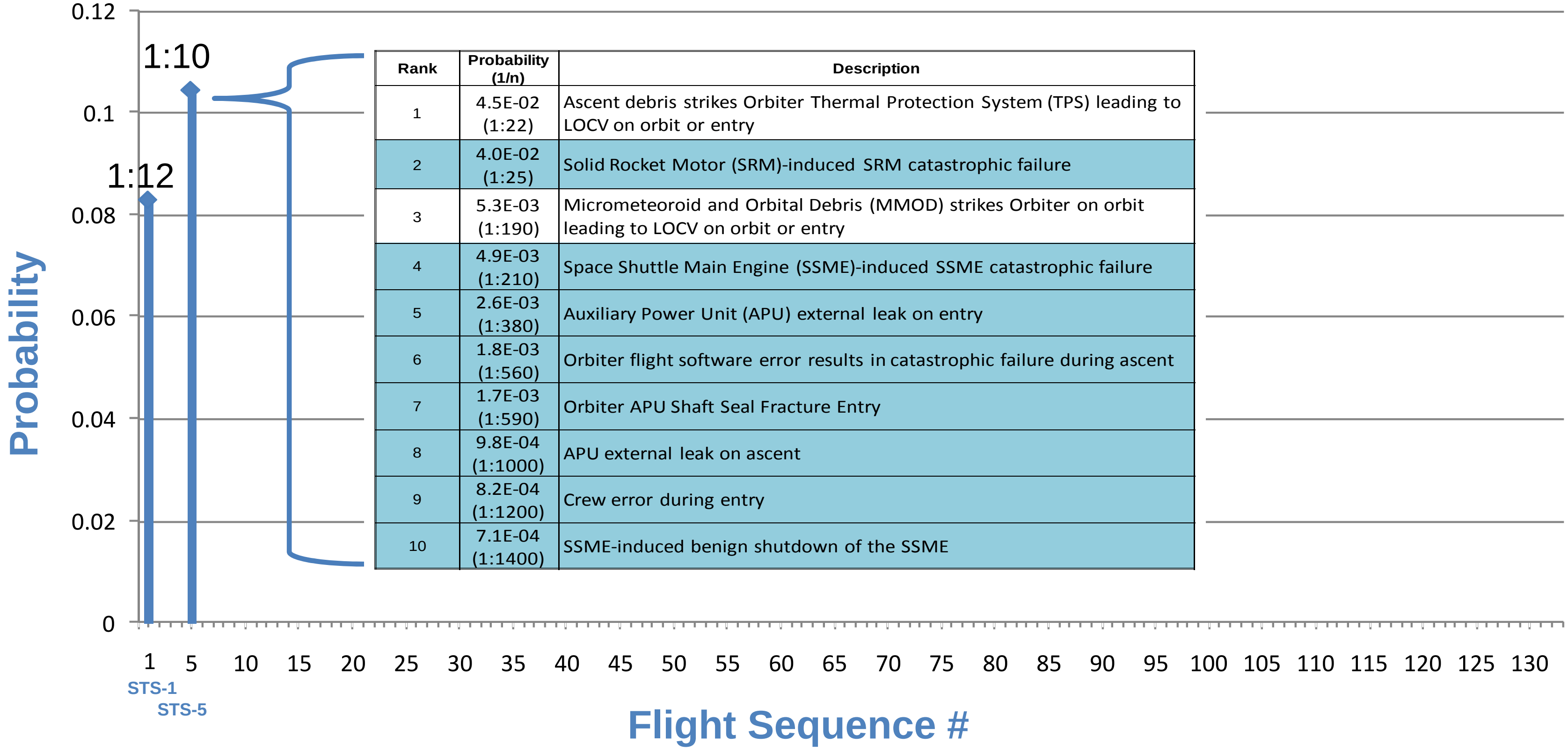
# RESULTS SUMMARY (STS-1)




| Rank | Probability (1/n) | Description |
|---|---|---|
| 1 | 4.5E-02 (1:22) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry |
| 2 | 1.6E-02 (1:63) | Solid Rocket Motor (SRM)-induced SRM catastrophic failure and ejection seats fail to save the crew |
| 3 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry |
| 4 | 4.2E-03 (1:240) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure and ejection seats fail to save the crew |
| 5 | 3.1E-03 (1:320) | Orbiter APU Shaft Seal Fracture Entry and ejection seats fail to save the crew |
| 6 | 2.4E-03 (1:420) | Auxiliary Power Unit (APU) external leak on entry and ejection seats fail to save the crew |
| 7 | 1.7E-03 (1:600) | Orbiter flight software error results in catastrophic failure during ascent and ejection seats fail to save the crew |
| 8 | 9.0E-04 (1:1100) | APU external leak on ascent and ejection seats fail to save the crew |
| 9 | 8.8E-04 (1:1100) | Orbiter APU Shaft Seal Fracture Ascent and ejection seats fail to save the crew |
| 10 | 6.3E-04 (1:1600) | SSME-induced benign shutdown of the SSME and ejection seats fail to save the crew |

- As stated previously STS-1 risk may have been higher due to unquantified risks
- As quantified STS-1 risk is dominated by Ascent debris and SRM risk

# RESULTS SUMMARY (STS-5)

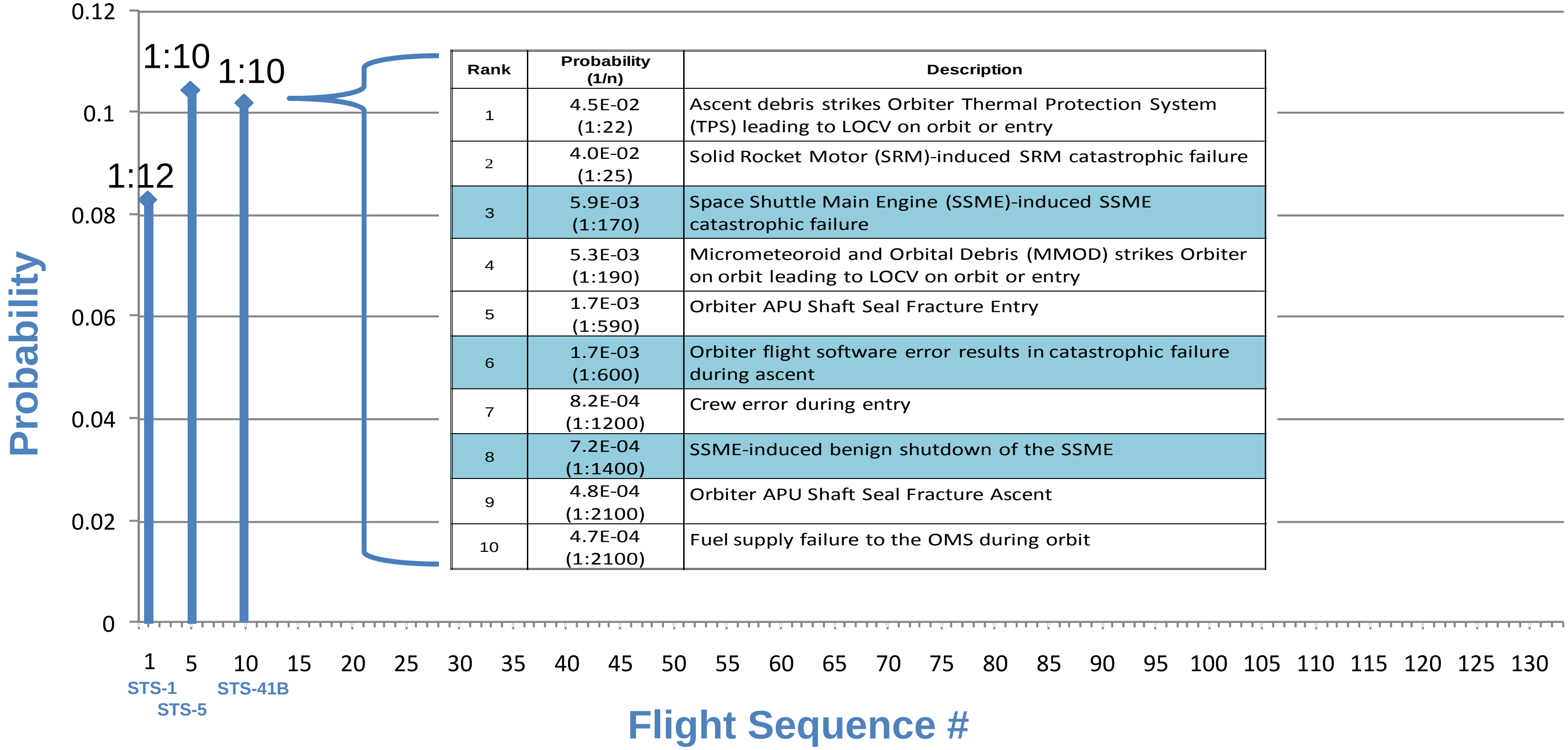



| Rank | Probability (1/n) | Description |
|---|---|---|
| 1 | 4.5E-02 (1:22) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry |
| 2 | 4.0E-02 (1:25) | Solid Rocket Motor (SRM)-induced SRM catastrophic failure |
| 3 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry |
| 4 | 4.9E-03 (1:210) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure |
| 5 | 2.6E-03 (1:380) | Auxiliary Power Unit (APU) external leak on entry |
| 6 | 1.8E-03 (1:560) | Orbiter flight software error results in catastrophic failure during ascent |
| 7 | 1.7E-03 (1:590) | Orbiter APU Shaft Seal Fracture Entry |
| 8 | 9.8E-04 (1:1000) | APU external leak on ascent |
| 9 | 8.2E-04 (1:1200) | Crew error during entry |
| 10 | 7.1E-04 (1:1400) | SSME-induced benign shutdown of the SSME |

- Ejection seats disabled, going from 2 to 4 crew
  - RSRM, SSME, APU external leaks, Orbiter Flight Software and Crew error on entry increase
- APU shaft seal fracture risk decreases due to changes in hydrazine detection criteria

**Blue highlight indicates risk has changed**

# RESULTS SUMMARY (STS-41B)

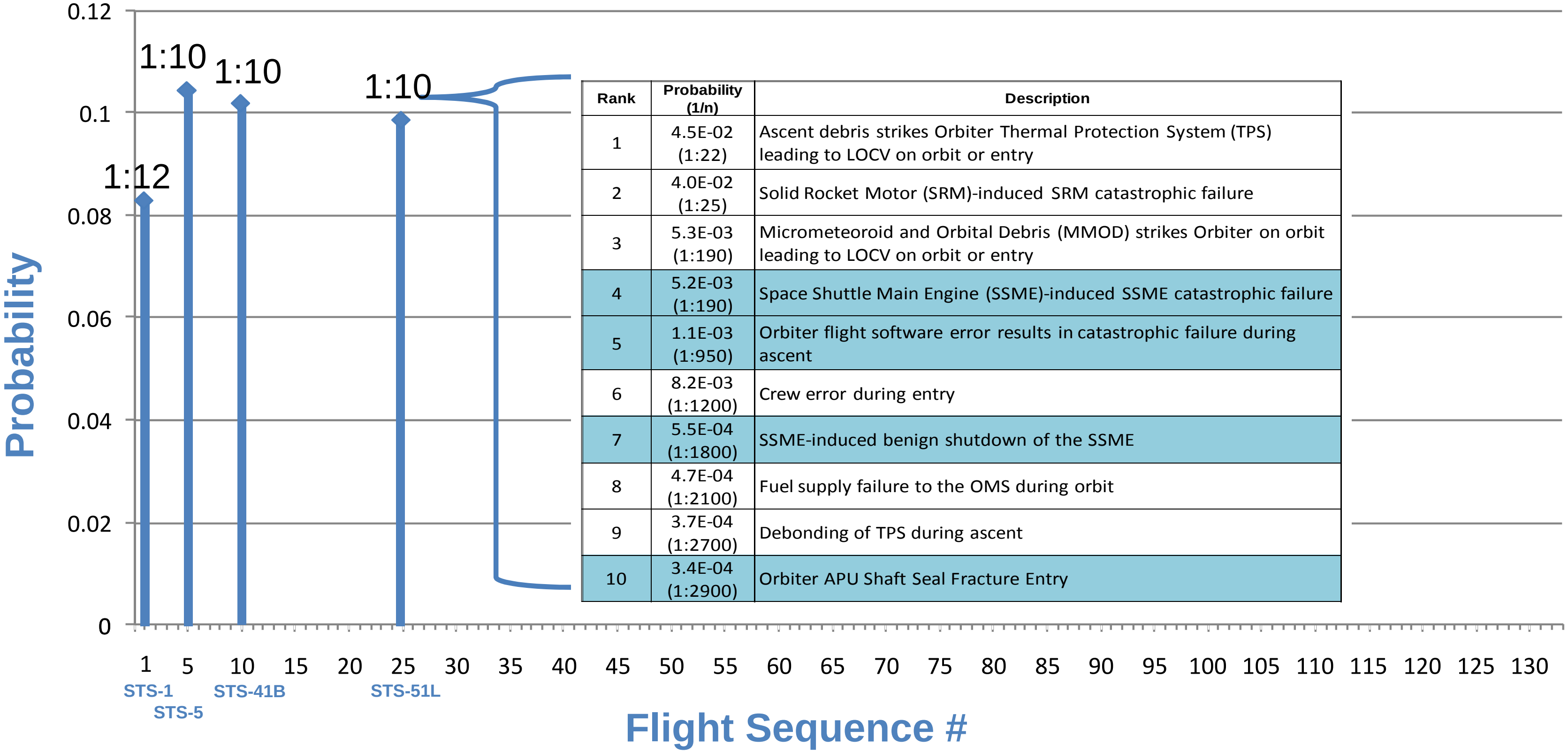



| Rank | Probability (1/n) | Description |
|---|---|---|
| 1 | 4.5E-02 (1:22) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry |
| 2 | 4.0E-02 (1:25) | Solid Rocket Motor (SRM)-induced SRM catastrophic failure |
| 3 | 5.9E-03 (1:170) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure |
| 4 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry |
| 5 | 1.7E-03 (1:590) | Orbiter APU Shaft Seal Fracture Entry |
| 6 | 1.7E-03 (1:600) | Orbiter flight software error results in catastrophic failure during ascent |
| 7 | 8.2E-04 (1:1200) | Crew error during entry |
| 8 | 7.2E-04 (1:1400) | SSME-induced benign shutdown of the SSME |
| 9 | 4.8E-04 (1:2100) | Orbiter APU Shaft Seal Fracture Ascent |
| 10 | 4.7E-04 (1:2100) | Fuel supply failure to the OMS during orbit |

- SSME Risk increases due to operating at a higher power level
- Orbiter flight software risk decreases due to use of OI-2 vs. OI-1
- APU risk decreases due to improvements made post STS-9 APU fire (processing changes), external leaks drops from top 10

**Blue highlight indicates risk has changed**

# RESULTS SUMMARY (STS-51L)

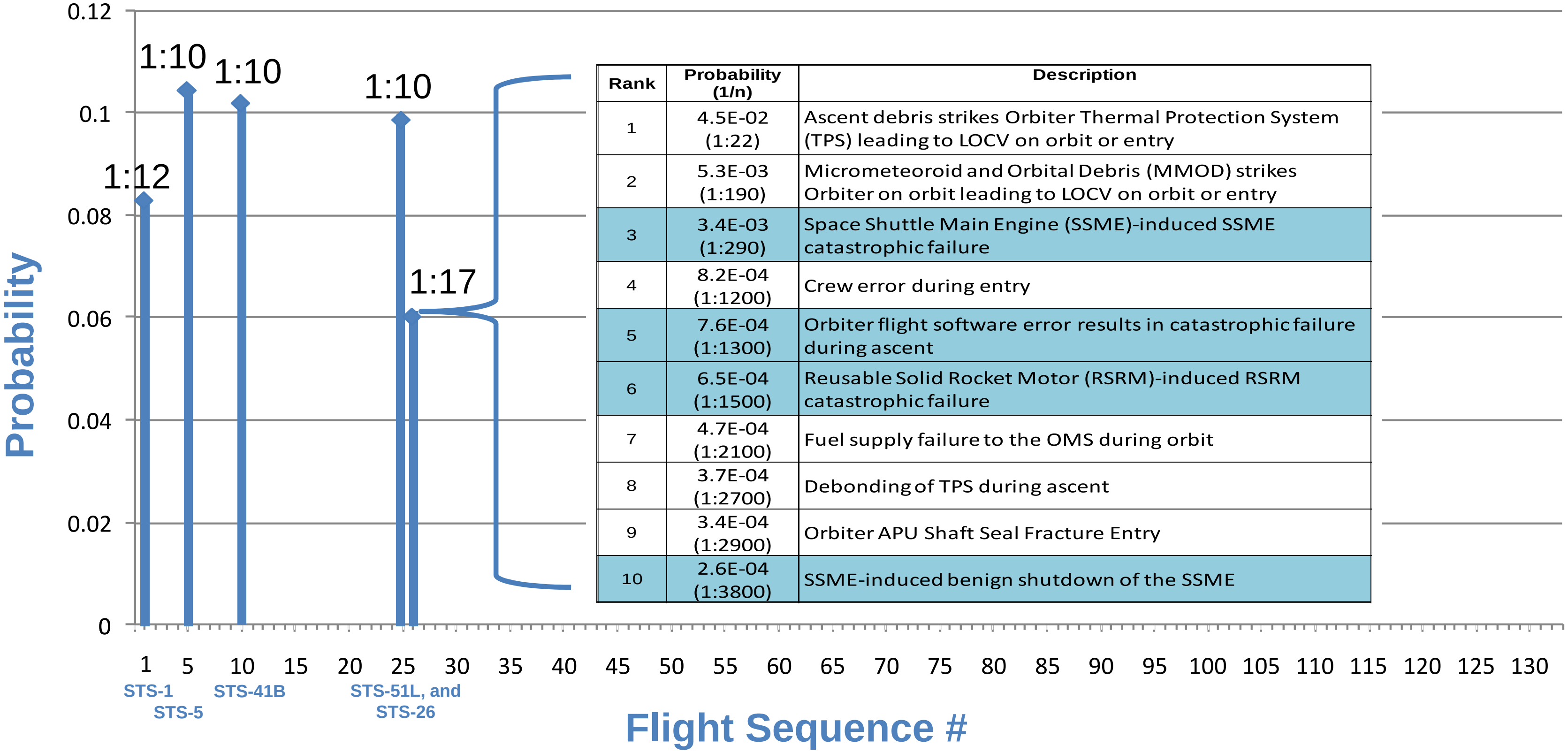



| Rank | Probability (1/n) | Description |
|---|---|---|
| 1 | 4.5E-02 (1:22) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry |
| 2 | 4.0E-02 (1:25) | Solid Rocket Motor (SRM)-induced SRM catastrophic failure |
| 3 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry |
| 4 | 5.2E-03 (1:190) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure |
| 5 | 1.1E-03 (1:950) | Orbiter flight software error results in catastrophic failure during ascent |
| 6 | 8.2E-03 (1:1200) | Crew error during entry |
| 7 | 5.5E-04 (1:1800) | SSME-induced benign shutdown of the SSME |
| 8 | 4.7E-04 (1:2100) | Fuel supply failure to the OMS during orbit |
| 9 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 10 | 3.4E-04 (1:2900) | Orbiter APU Shaft Seal Fracture Entry |

- Orbiter flight software risk decreases due to use of OI-7 vs. OI-2
- APU risk decreases due to improvements made post STS-9 APU fire (injector re-design)
- SSME Benign shutdown risk decrease slightly due to decreases in Orbiter Flight software and APU

**Blue highlight indicates risk has changed**

# RESULTS SUMMARY (STS-26)

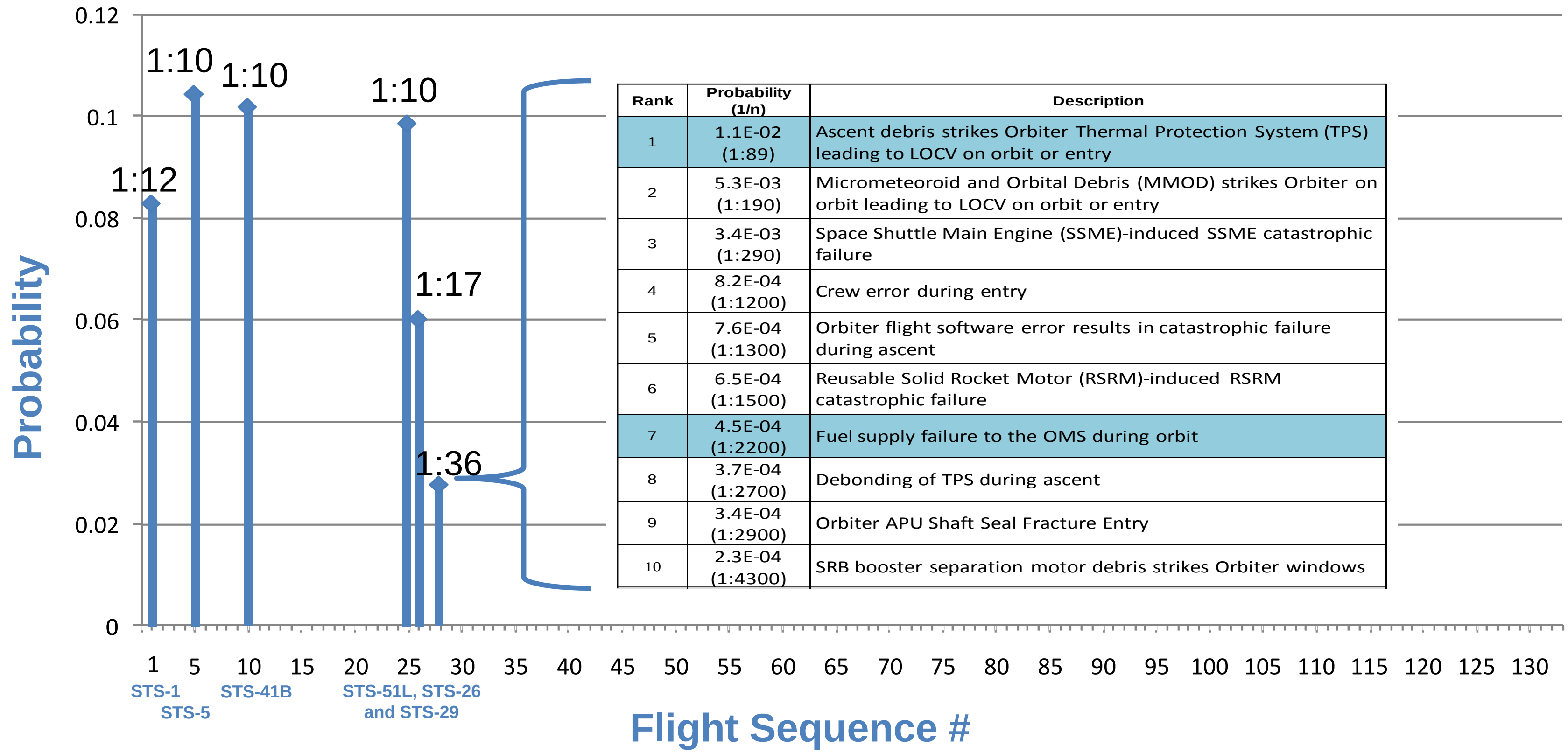



| Rank | Probability (1/n) | Description |
|---|---|---|
| 1 | 4.5E-02 (1:22) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry |
| 2 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry |
| 3 | 3.4E-03 (1:290) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure |
| 4 | 8.2E-04 (1:1200) | Crew error during entry |
| 5 | 7.6E-04 (1:1300) | Orbiter flight software error results in catastrophic failure during ascent |
| 6 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure |
| 7 | 4.7E-04 (1:2100) | Fuel supply failure to the OMS during orbit |
| 8 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 9 | 3.4E-04 (1:2900) | Orbiter APU Shaft Seal Fracture Entry |
| 10 | 2.6E-04 (1:3800) | SSME-induced benign shutdown of the SSME |

- RSRM risk decreases from 1:25 to 1:1500 due to re-design post *Challenger*
- SSME risk decreases due to corrective actions following failures and engine upgrade from FPL to Phase II engine
- Orbiter flight software risk decreases due to use of OI-8B vs. OI-7

**Blue highlight indicates risk has changed**

# RESULTS SUMMARY (STS-29)

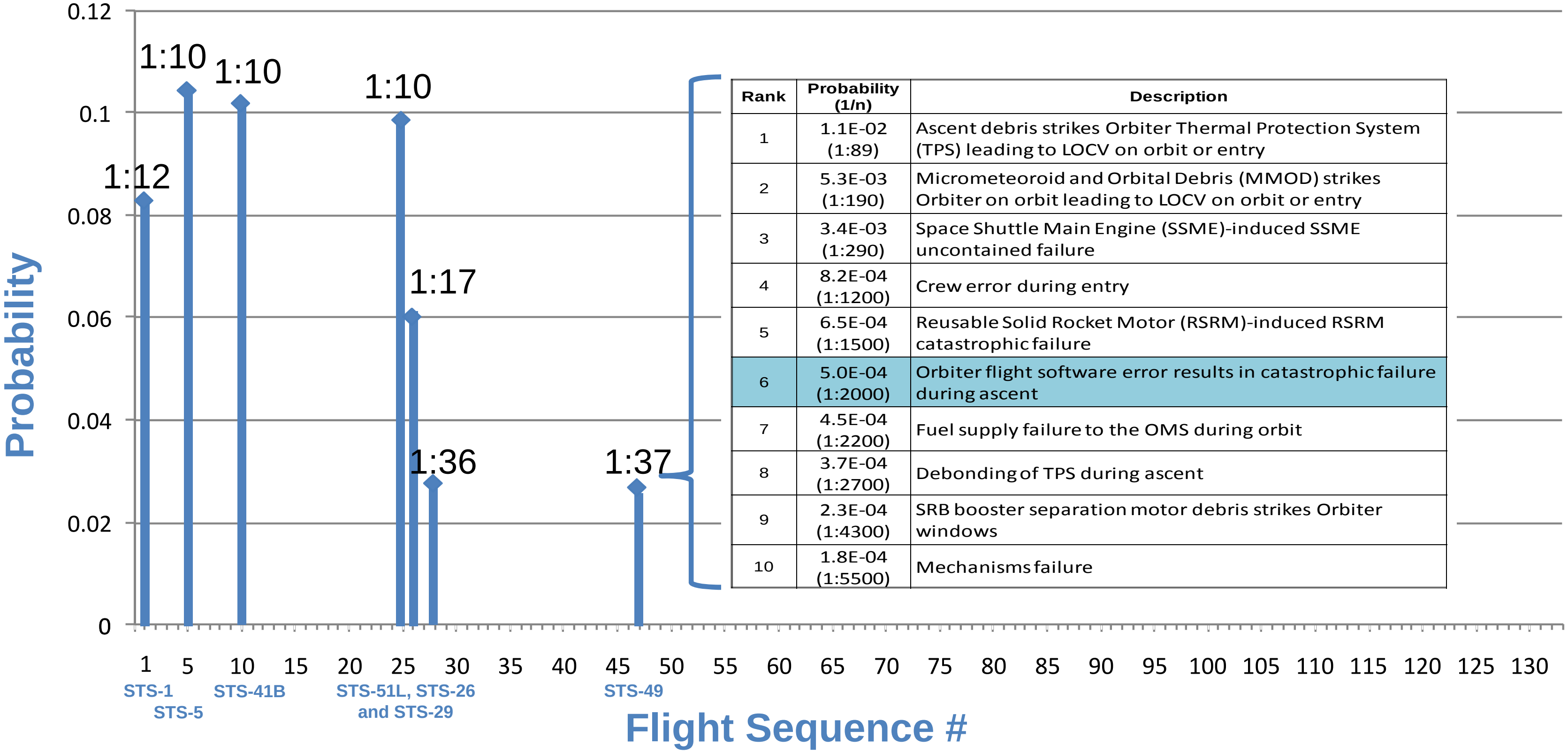



| Rank | Probability (1/n) | Description |
|---|---|---|
| 1 | 1.1E-02 (1:89) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry |
| 2 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry |
| 3 | 3.4E-03 (1:290) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure |
| 4 | 8.2E-04 (1:1200) | Crew error during entry |
| 5 | 7.6E-04 (1:1300) | Orbiter flight software error results in catastrophic failure during ascent |
| 6 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure |
| 7 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit |
| 8 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 9 | 3.4E-04 (1:2900) | Orbiter APU Shaft Seal Fracture Entry |
| 10 | 2.3E-04 (1:4300) | SRB booster separation motor debris strikes Orbiter windows |

- Ascent Debris risk decreases from 1:22 to 1:89 due to SRB nose cap TPS re-design post STS-27. After this mission the Orbiter damages are <100 damages per flight (with the exception of STS-86 through STS-93)
- SSME benign shutdown risk drops from the top 10 due to the Ascent debris risk reduction (i.e. reduction of critical TPS damage combined with SSME benign shutdown)
- OMS fuel supply risk decreases slightly due to He Regulator changes

**Blue highlight indicates risk has changed**

# RESULTS SUMMARY (STS-49)



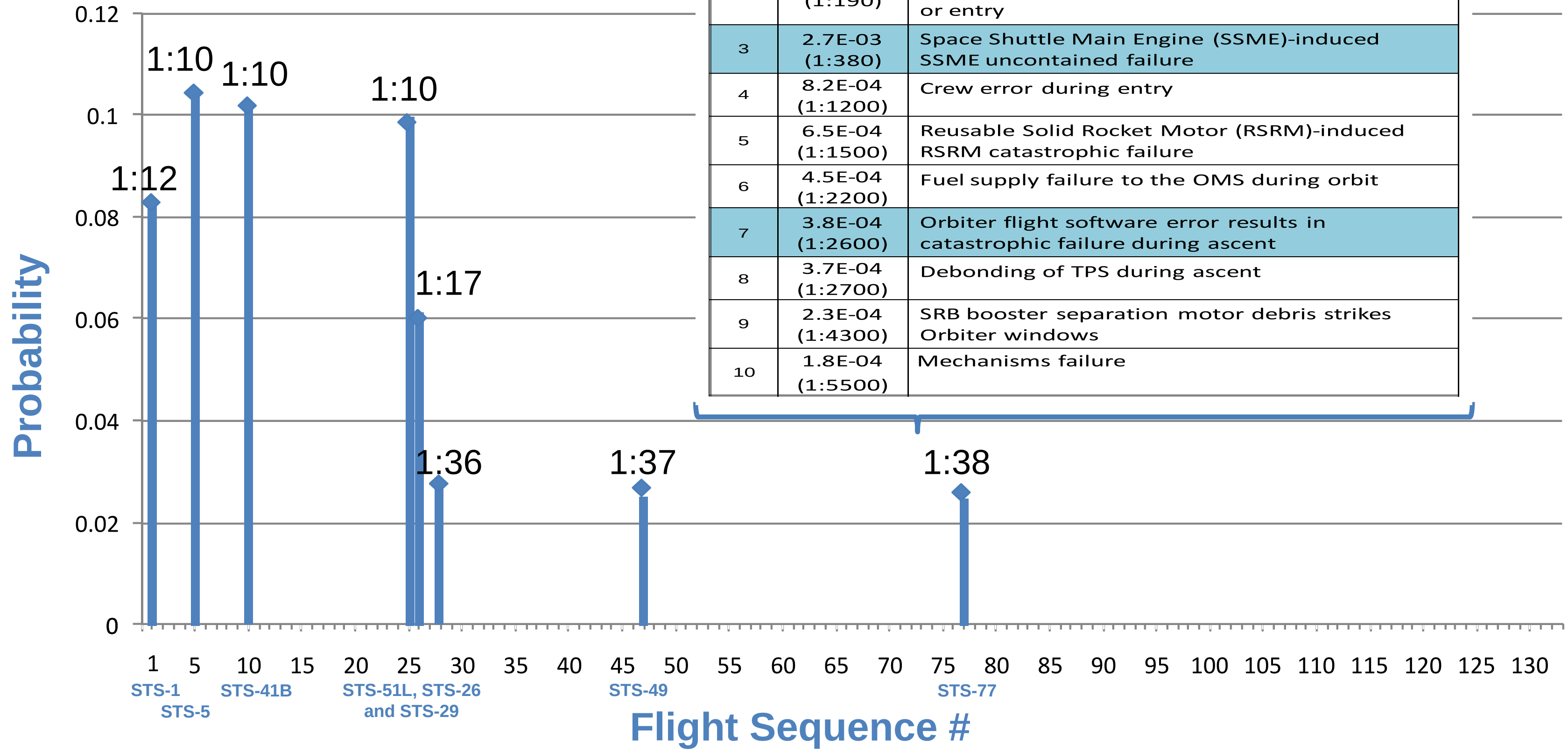

| Rank | Probability (1/n) | Description |
|---|---|---|
| 1 | 1.1E-02 (1:89) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry |
| 2 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry |
| 3 | 3.4E-03 (1:290) | Space Shuttle Main Engine (SSME)-induced SSME uncontained failure |
| 4 | 8.2E-04 (1:1200) | Crew error during entry |
| 5 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure |
| 6 | 5.0E-04 (1:2000) | Orbiter flight software error results in catastrophic failure during ascent |
| 7 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit |
| 8 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 9 | 2.3E-04 (1:4300) | SRB booster separation motor debris strikes Orbiter windows |
| 10 | 1.8E-04 (1:5500) | Mechanisms failure |

- Orbiter flight software risk decreases due to use of OI-21 vs. OI-8B
- SSME benign shutdown risk drops from top 10 due to Orbiter flight software risk decrease
- APU risk drops from the top 10
  - Orbiter APU shaft seal risk eliminated due to IAPU re-design

**Blue highlight indicates risk has changed**

# RESULTS SUMMARY (STS-77)

| Rank | Probability (1/n) | Description |
|---|---|---|
| 1 | 1.1E-02 (1:89) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry |
| 2 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry |
| 3 | 2.7E-03 (1:380) | Space Shuttle Main Engine (SSME)-induced SSME uncontained failure |
| 4 | 8.2E-04 (1:1200) | Crew error during entry |
| 5 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure |
| 6 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit |
| 7 | 3.8E-04 (1:2600) | Orbiter flight software error results in catastrophic failure during ascent |
| 8 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 9 | 2.3E-04 (1:4300) | SRB booster separation motor debris strikes Orbiter windows |
| 10 | 1.8E-04 (1:5500) | Mechanisms failure |

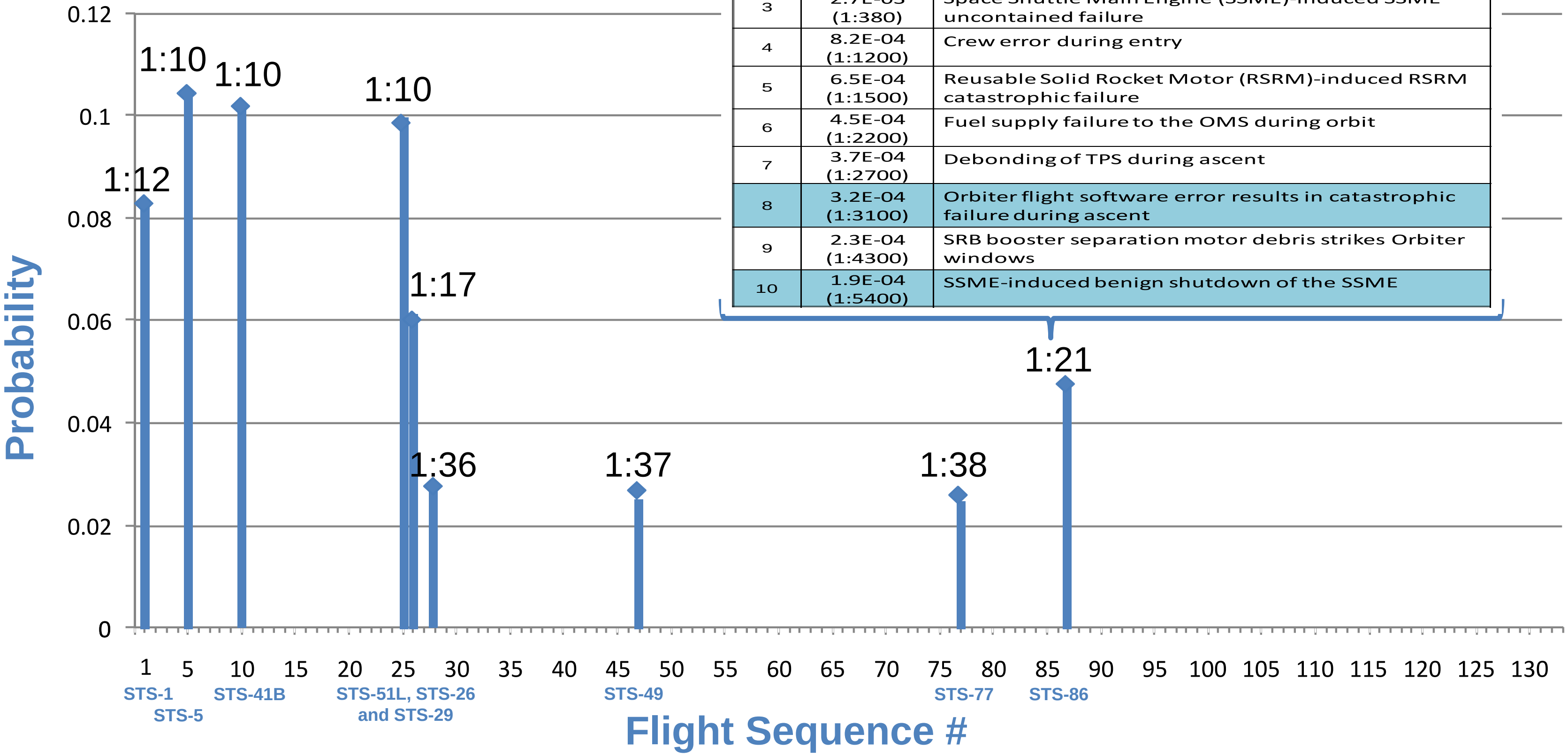



- Orbiter flight software risk decreases due to use of OI-24 vs. OI-21
- SSME risk decreases due to corrective actions following failures, engine upgrade from phase II to Block I/IA and the introduction of HPOTP-AT

**Blue highlight indicates risk has changed**

# RESULTS SUMMARY (STS-86)

| Rank | Probability (1/n) | Description |
|---|---|---|
| 1 | 3.4E-02 (1:30) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry |
| 2 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry |
| 3 | 2.7E-03 (1:380) | Space Shuttle Main Engine (SSME)-induced SSME uncontained failure |
| 4 | 8.2E-04 (1:1200) | Crew error during entry |
| 5 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure |
| 6 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit |
| 7 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 8 | 3.2E-04 (1:3100) | Orbiter flight software error results in catastrophic failure during ascent |
| 9 | 2.3E-04 (1:4300) | SRB booster separation motor debris strikes Orbiter windows |
| 10 | 1.9E-04 (1:5400) | SSME-induced benign shutdown of the SSME |

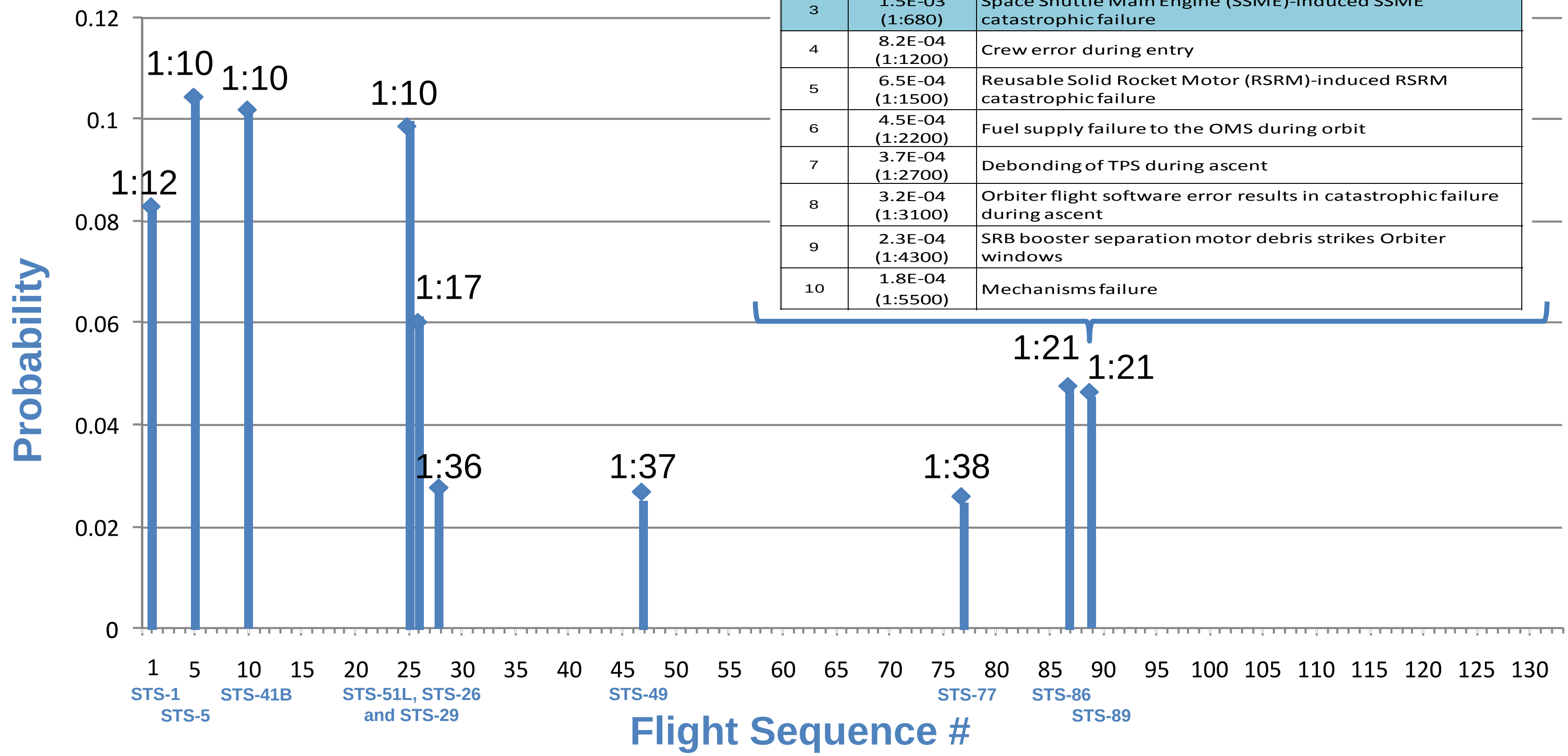



- Ascent debris risk significantly increases due to new foam application process initiated ET acreage due to EPA banning of CFC-11 Freon. Average number of Orbiter damages increases from ~13 to ~45 with STS-87 experiencing 109 lower surface damages
- Orbiter flight software risk decreases due to use of OI-26 vs. OI-24
- SSME Shutdown risk increased due to the increase in Ascent Debris

**Blue highlight indicates risk has changed**

# RESULTS SUMMARY (STS-89)

| Rank | Probability (1/n) | Description |
|---|---|---|
| 1 | 3.4E-02 (1:30) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry |
| 2 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry |
| 3 | 1.5E-03 (1:680) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure |
| 4 | 8.2E-04 (1:1200) | Crew error during entry |
| 5 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure |
| 6 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit |
| 7 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 8 | 3.2E-04 (1:3100) | Orbiter flight software error results in catastrophic failure during ascent |
| 9 | 2.3E-04 (1:4300) | SRB booster separation motor debris strikes Orbiter windows |
| 10 | 1.8E-04 (1:5500) | Mechanisms failure |

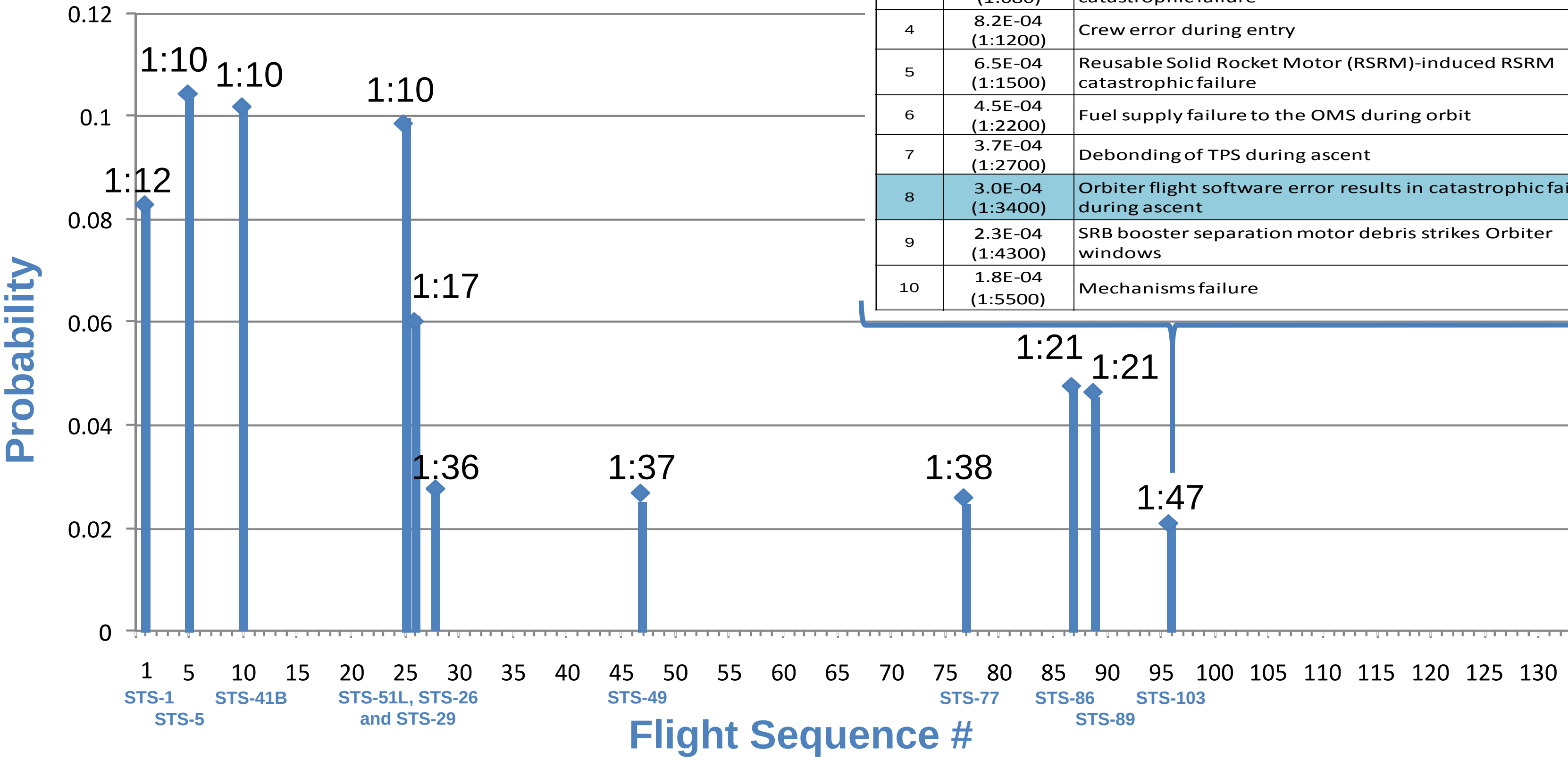



- SSME risk decreases due to engine upgrade from Block I and IA engine to Block II engine and the introduction of LTMCC

**Blue highlight indicates risk has changed**

# RESULTS SUMMARY (STS-103)

| Rank | Probability (1/n) | Description |
|---|---|---|
| 1 | 7.9E-03 (1:130) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry |
| 2 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry |
| 3 | 1.5E-03 (1:680) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure |
| 4 | 8.2E-04 (1:1200) | Crew error during entry |
| 5 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure |
| 6 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit |
| 7 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 8 | 3.0E-04 (1:3400) | Orbiter flight software error results in catastrophic failure during ascent |
| 9 | 2.3E-04 (1:4300) | SRB booster separation motor debris strikes Orbiter windows |
| 10 | 1.8E-04 (1:5500) | Mechanisms failure |

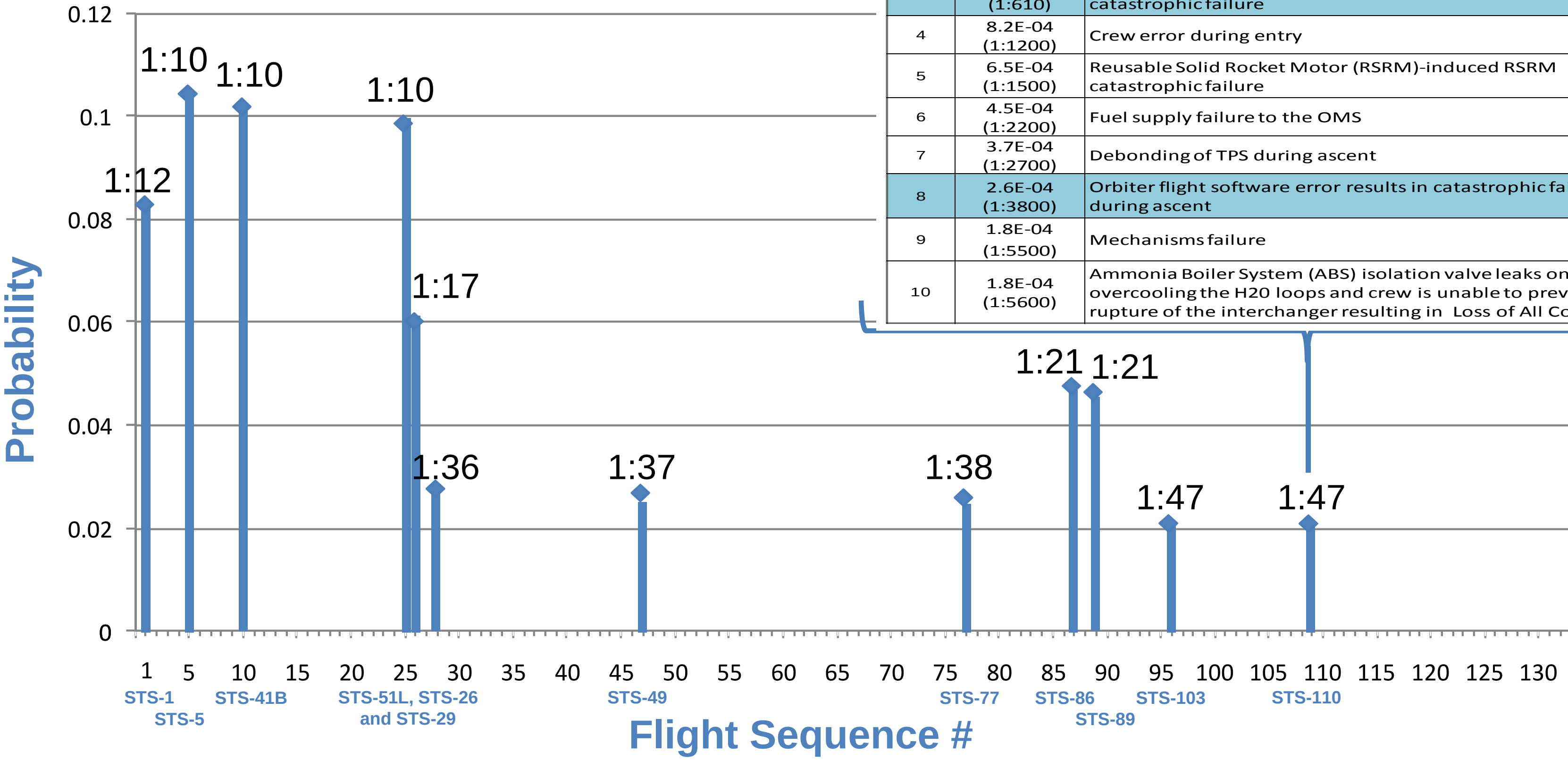



- Ascent Debris risk significantly decreases due to ET foam venting holes (average # of damages goes back down to ~16 from ~45)
- Orbiter flight software risk decreases due to use of OI-26B vs. OI-26

**Blue highlight indicates risk has changed**

# RESULTS SUMMARY (STS-110)

| Rank | Probability (1/n) | Description |
|---|---|---|
| 1 | 7.9E-03 (1:130) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry |
| 2 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry |
| 3 | 1.6E-03 (1:610) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure |
| 4 | 8.2E-04 (1:1200) | Crew error during entry |
| 5 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure |
| 6 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS |
| 7 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 8 | 2.6E-04 (1:3800) | Orbiter flight software error results in catastrophic failure during ascent |
| 9 | 1.8E-04 (1:5500) | Mechanisms failure |
| 10 | 1.8E-04 (1:5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling |

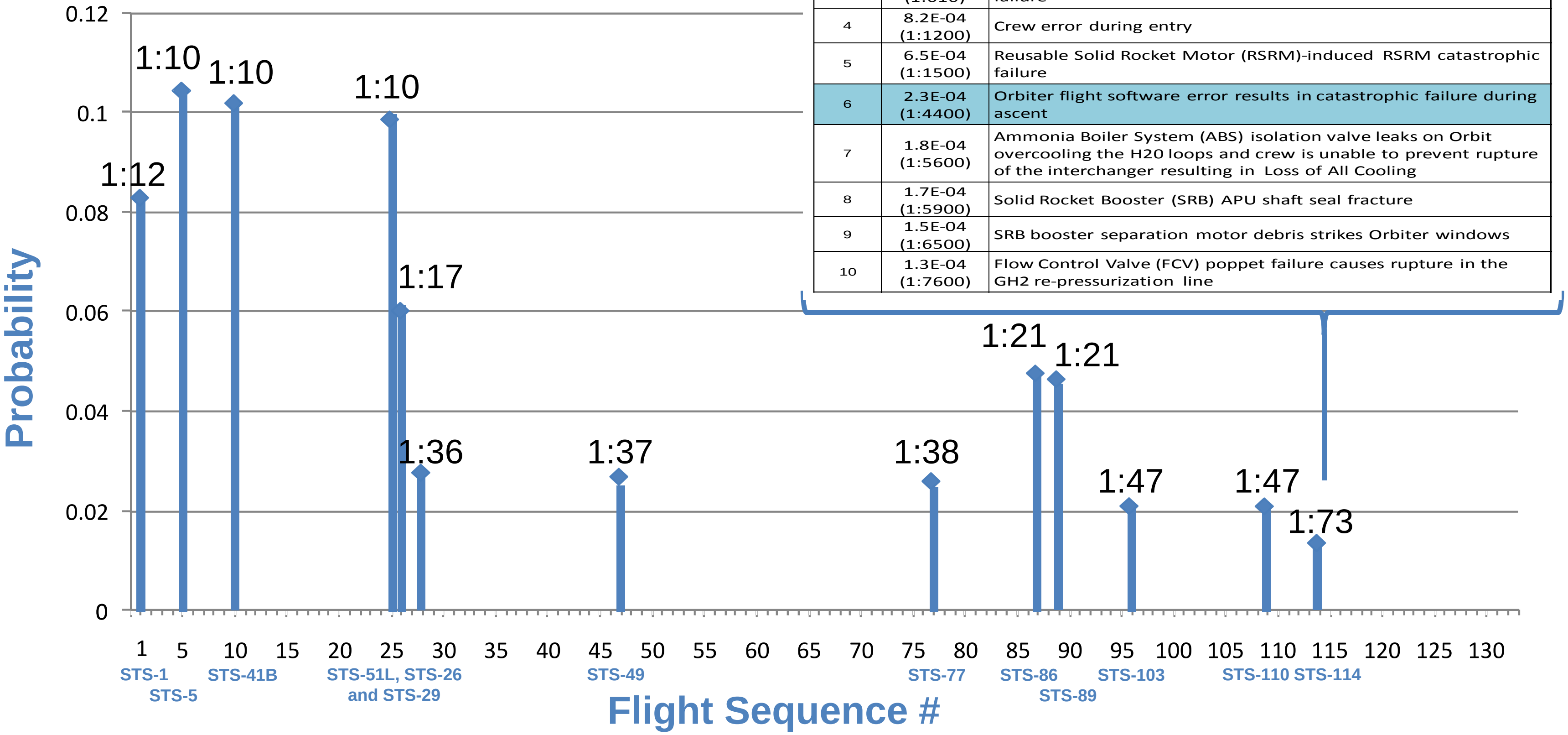



- Orbiter flight software risk decreases due to use of OI-29 vs. OI-26B
- SSME risk increases due to engine upgrade from Block IIA to Block II and the introduction of HPFTP-AT
  - There were three early HPFTP-AT related failures. Although heavily discounted due to improvements, risk still increases.

**Blue highlight indicates risk has changed**

# RESULTS SUMMARY (STS-114)

| Rank | Probability (1/n) | Description |
|---|---|---|
| 1 | 5.1E-03 (1:200) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry |
| 2 | 1.7E-03 (1:600) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry |
| 3 | 1.6E-03 (1:610) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure |
| 4 | 8.2E-04 (1:1200) | Crew error during entry |
| 5 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure |
| 6 | 2.3E-04 (1:4400) | Orbiter flight software error results in catastrophic failure during ascent |
| 7 | 1.8E-04 (1:5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling |
| 8 | 1.7E-04 (1:5900) | Solid Rocket Booster (SRB) APU shaft seal fracture |
| 9 | 1.5E-04 (1:6500) | SRB booster separation motor debris strikes Orbiter windows |
| 10 | 1.3E-04 (1:7600) | Flow Control Valve (FCV) poppet failure causes rupture in the GH2 re-pressurization line |

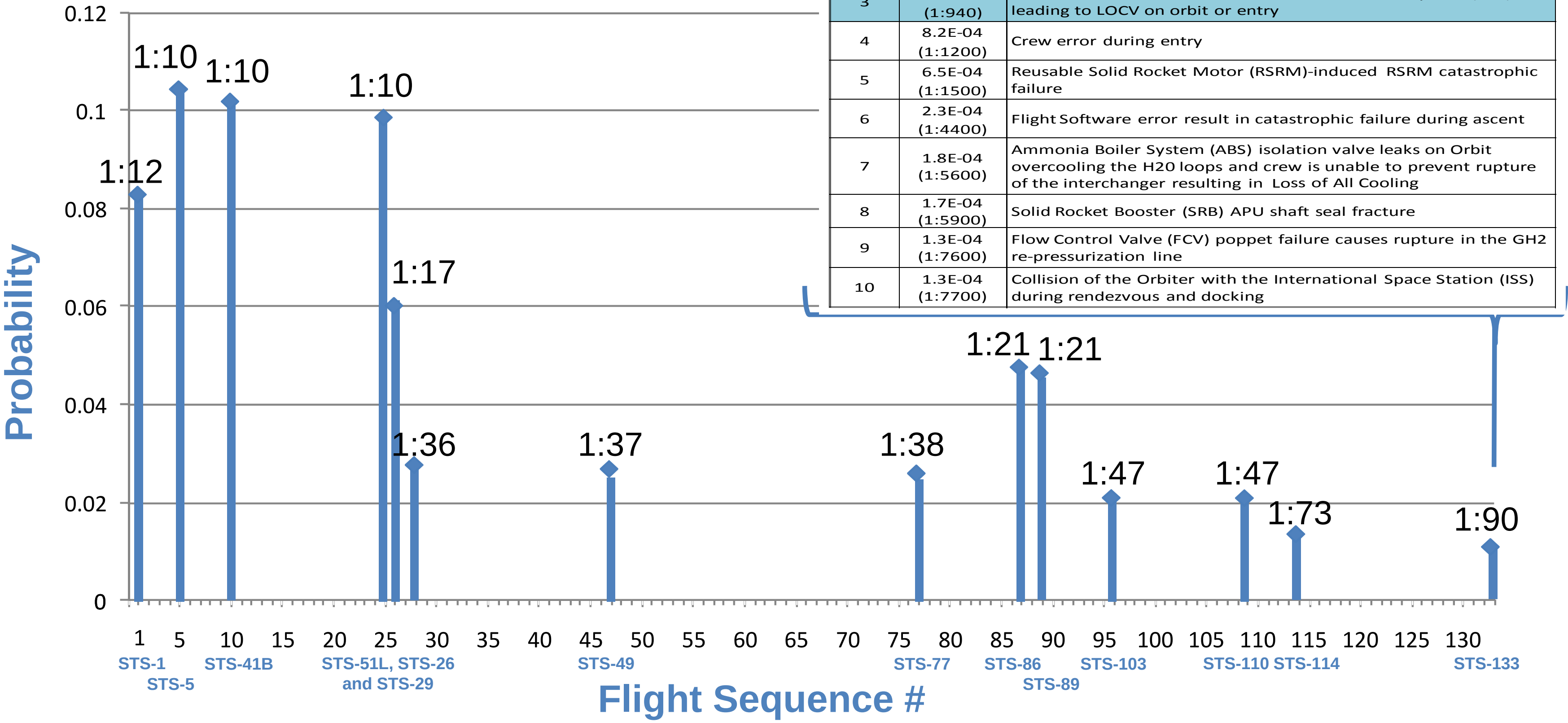



- MMOD risk decreases due to FD2 inspection with repair and crew rescue (no late inspection)
- Ascent debris risk decreases due to FD2 inspection with repair and crew rescue
- Orbiter flight software risk reduction due to use of OI-30 vs. OI-29
- TPS debond risk drops from top 10 due to FD2 inspection with repair and crew rescue
- OMS fuel supply risk drops from top 10 due to crew rescue capability

**Blue highlight indicates risk has changed**

# RESULTS SUMMARY (STS-133)

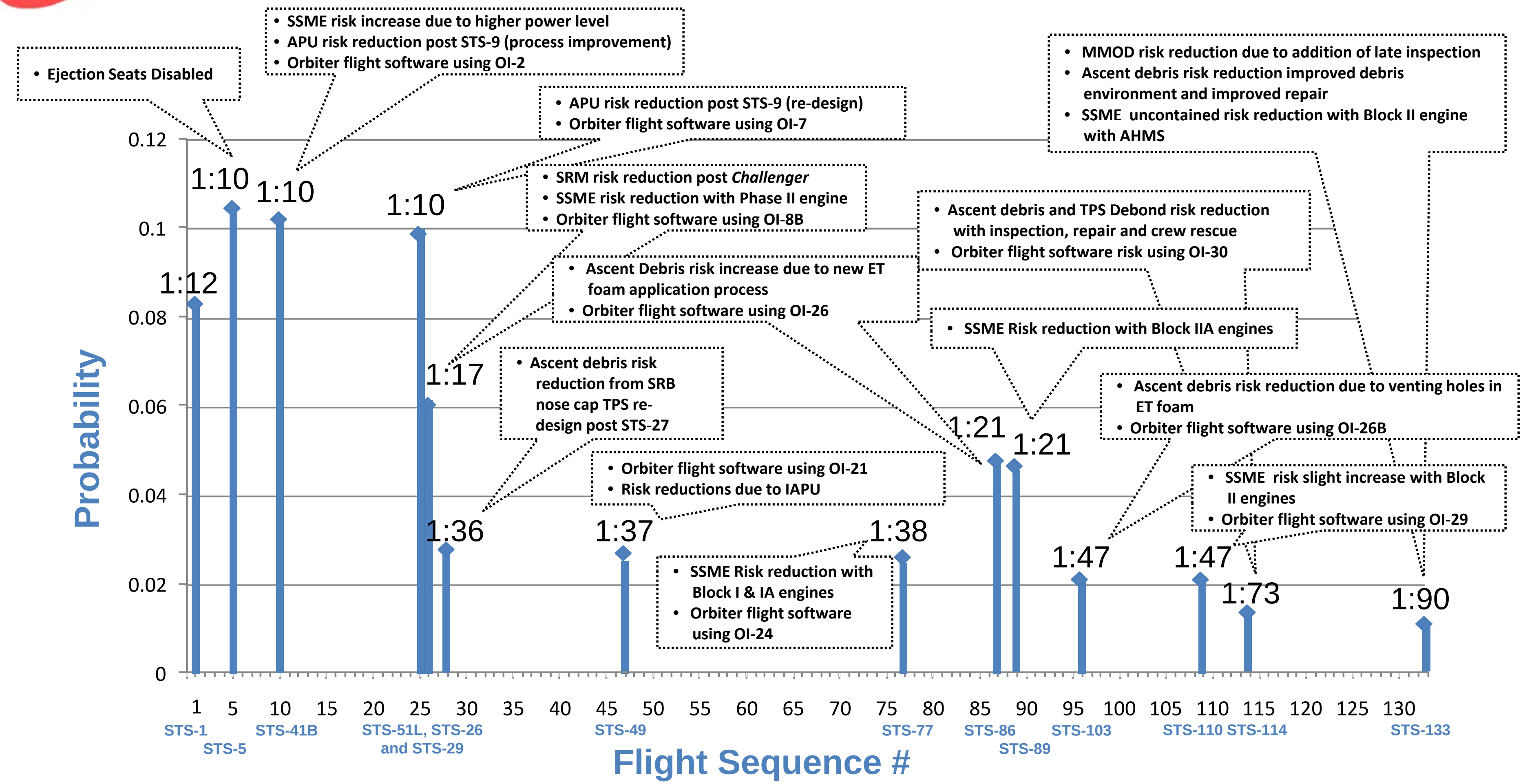
| Rank | Probability (1/n) | Description |
|---|---|---|
| 1 | 3.3E-03 (1:300) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry |
| 2 | 1.5E-03 (1:650) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure |
| 3 | 1.1E-03 (1:940) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry |
| 4 | 8.2E-04 (1:1200) | Crew error during entry |
| 5 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure |
| 6 | 2.3E-04 (1:4400) | Flight Software error result in catastrophic failure during ascent |
| 7 | 1.8E-04 (1:5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling |
| 8 | 1.7E-04 (1:5900) | Solid Rocket Booster (SRB) APU shaft seal fracture |
| 9 | 1.3E-04 (1:7600) | Flow Control Valve (FCV) poppet failure causes rupture in the GH2 re-pressurization line |
| 10 | 1.3E-04 (1:7700) | Collision of the Orbiter with the International Space Station (ISS) during rendezvous and docking |




- MMOD risk decreases due to late inspection with improved repair and crew rescue
- SSME risk decreases due to addition of Advanced Health Monitoring System (AHMS)
- Ascent debris decrease due improved debris environment and improved repair and crew rescue
- SRB booster separation motor debris drops from the top 10 due to process improvements

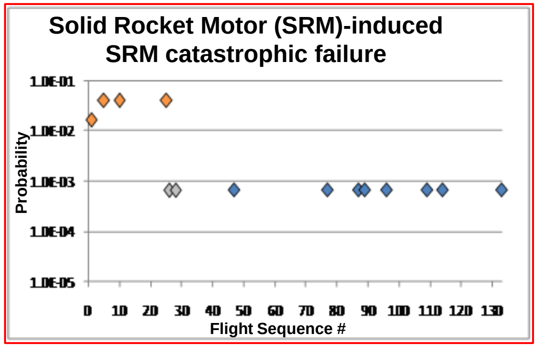
**Blue highlight indicates risk has changed**

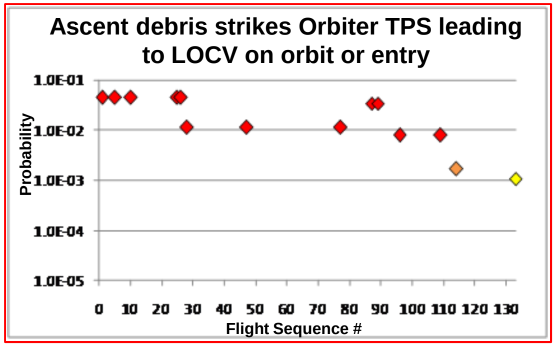
# RESULTS SUMMARY

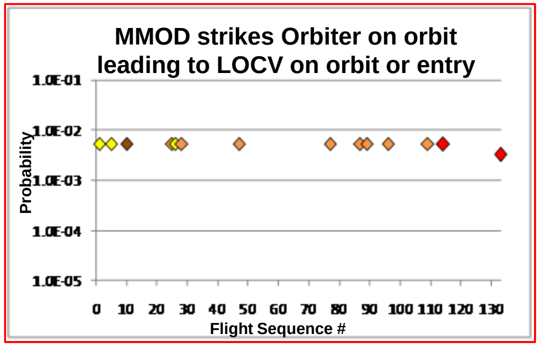


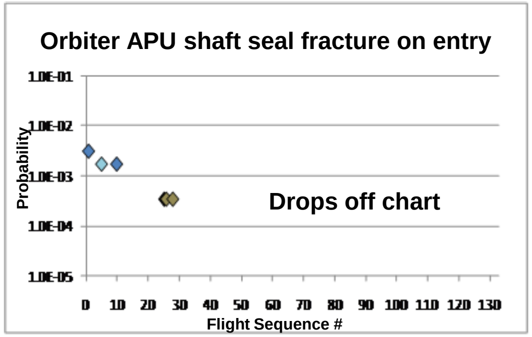

- There was an 8% likelihood of making it to flight 25 without LOCV and a 8% likelihood of making it from flight 26 to flight 113 without LOCV using the values on this chart
  - We were lucky, there were a number of close calls (e.g. STS-9 APU fire, STS-27 Ascent Debris, STS-95 drag chute door)

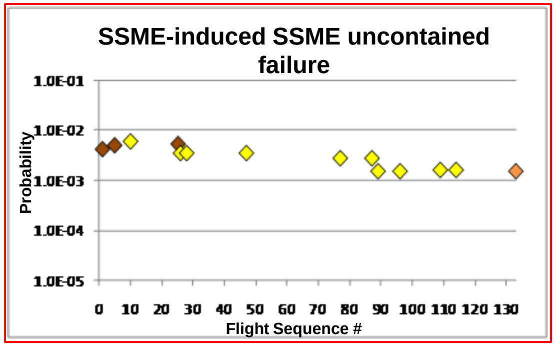
# HOW TOP 10 RISKS CHANGE OVER TIME

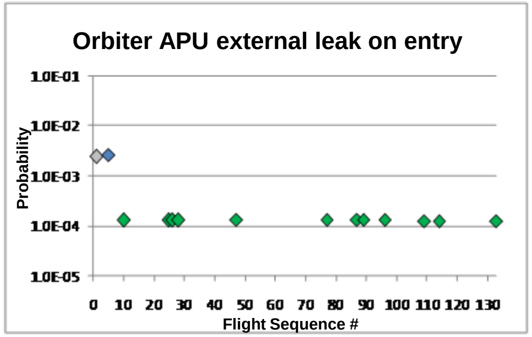


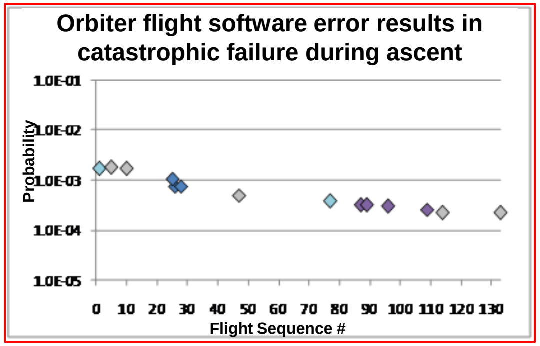



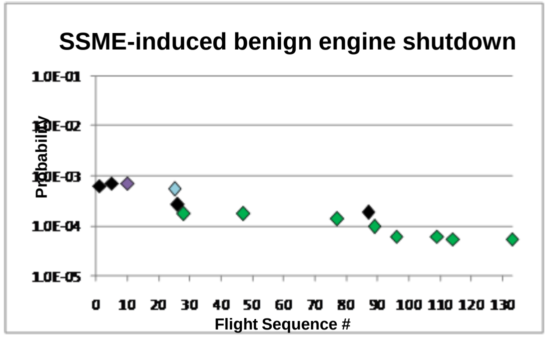



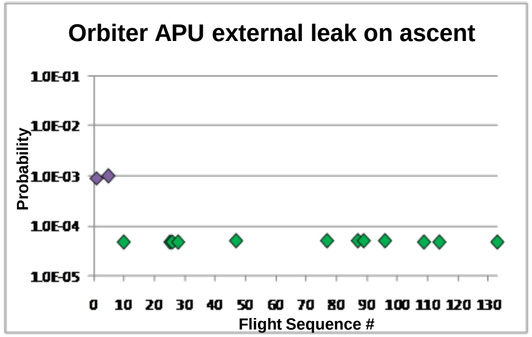



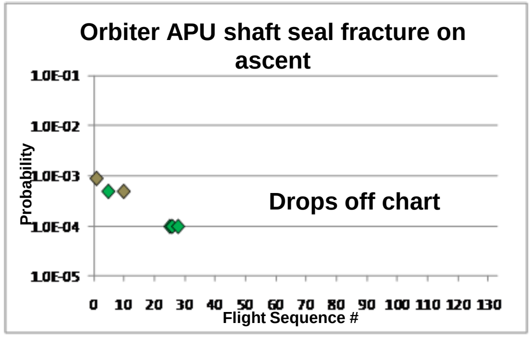



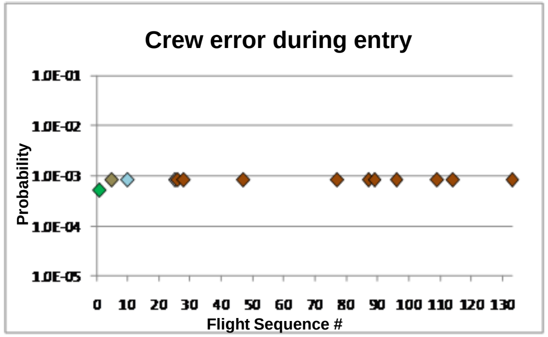

| Risk Rank |
|---|
| 1 |
| 2 |
| 3 |
| 4 |
| 5 |
| 6 |
| 7 |
| 8 |
| 9 |
| 10 |
| OTHER |

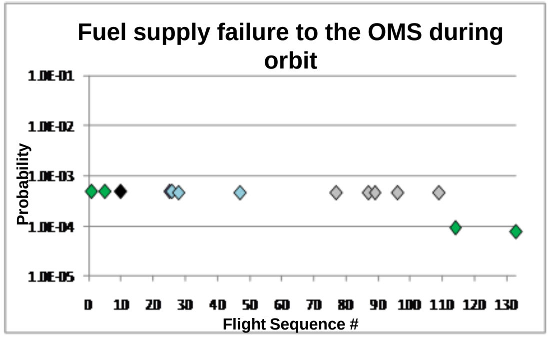
**Red outline indicates a risk that is always in the top 10 risks**

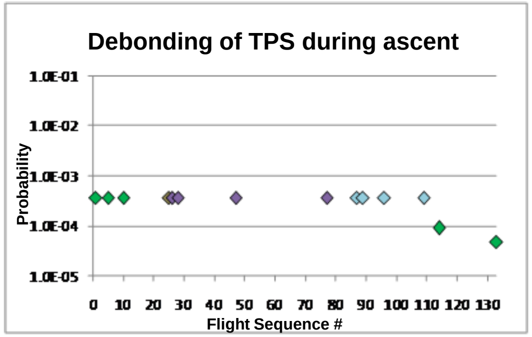
**Additional details on top 10 risks for each flight provided in backup**

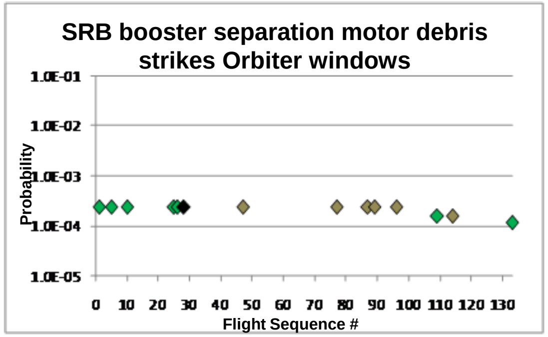
# HOW TOP 10 RISKS CHANGE OVER TIME (2)

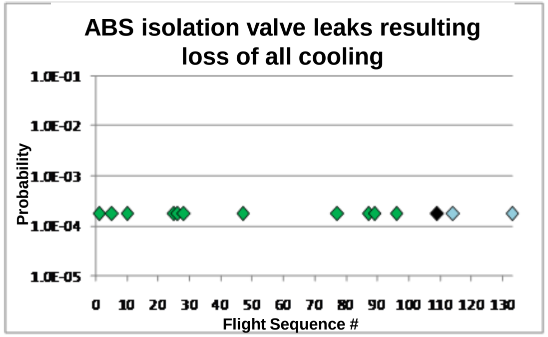


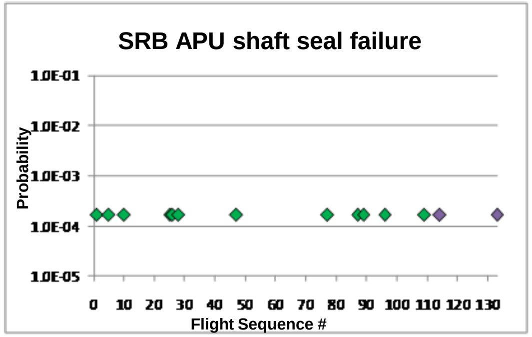



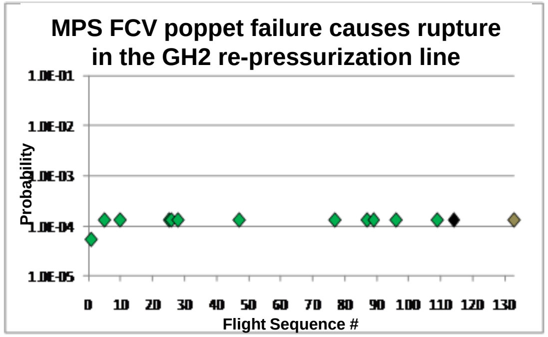



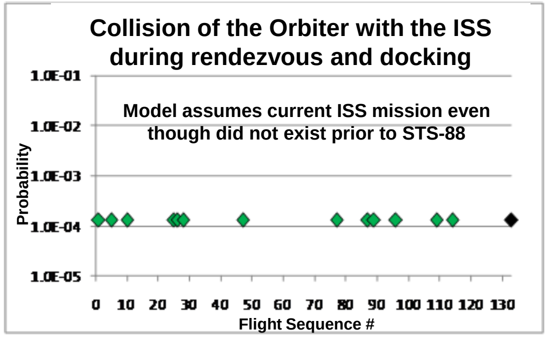



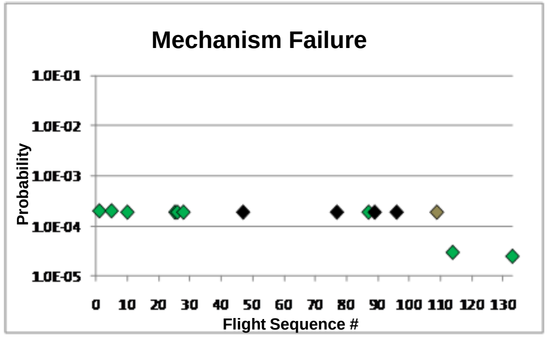




| Risk Rank | |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 10 | |
| OTHER | |

**Additional details on top 10 risks for each flight provided in backup**

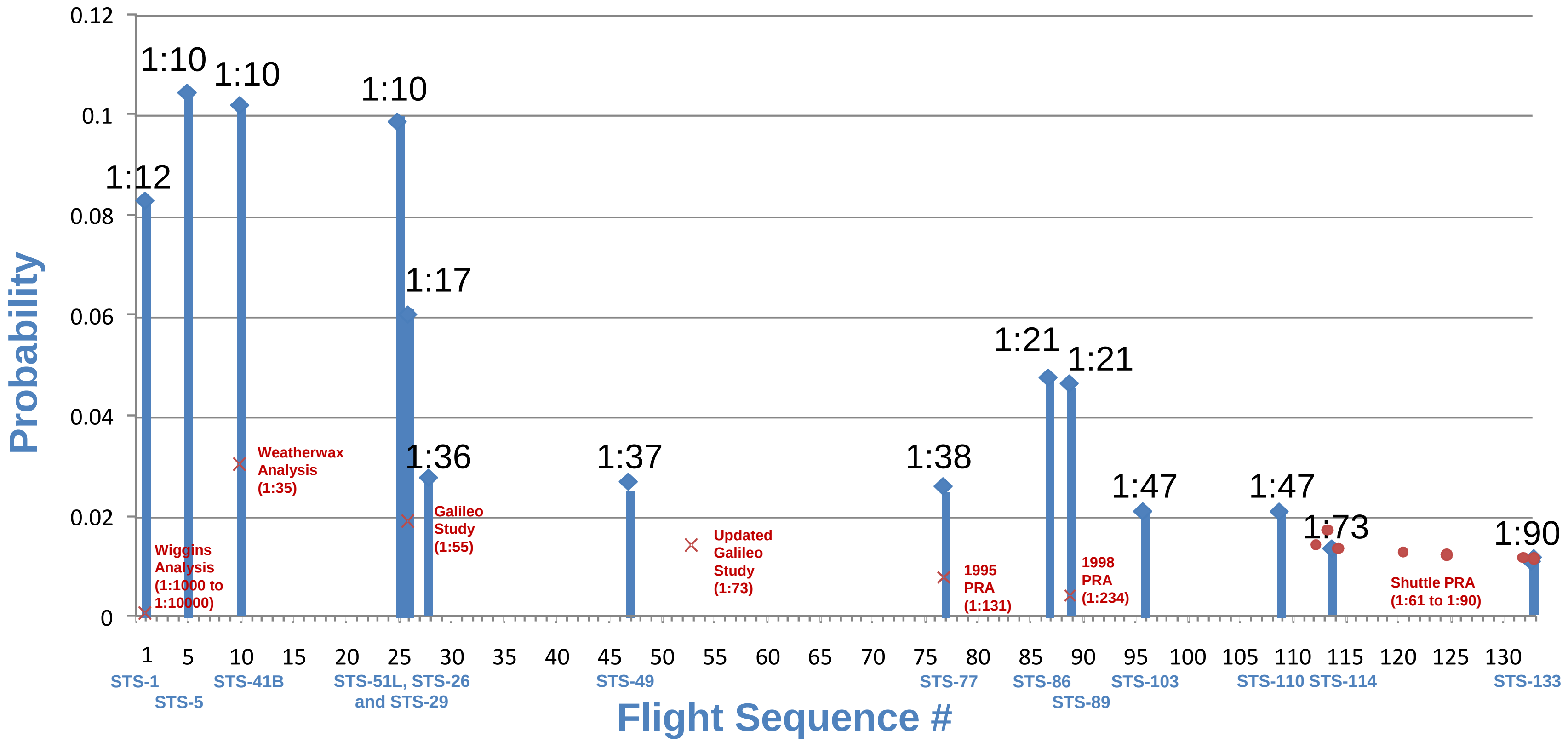
# HOW TOP 10 RISKS CHANGE OVER TIME (3)




| Risk Rank | |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 10 | |
| OTHER | |

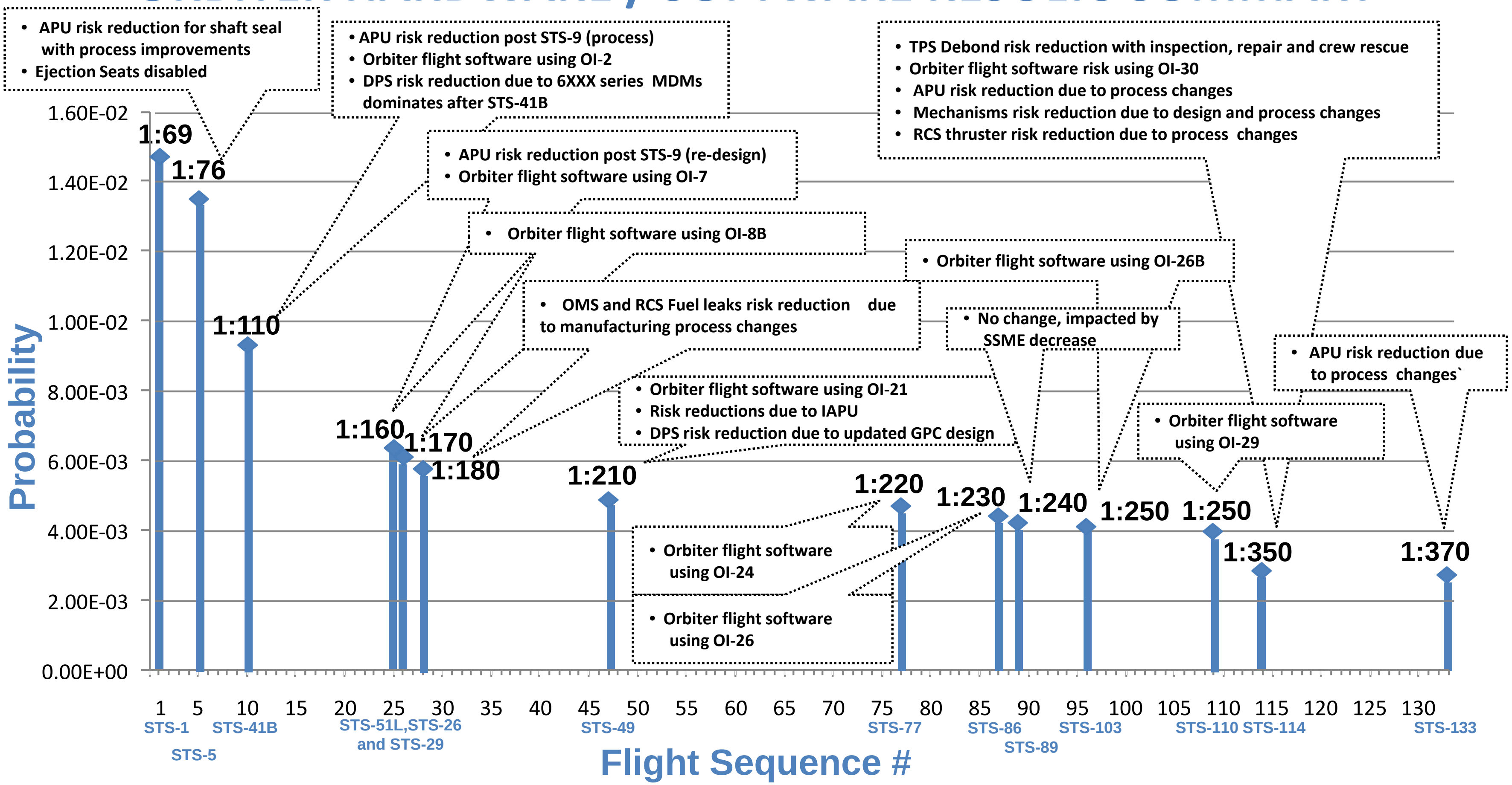
**Additional details on top 10 risks for each flight provided in backup**

# RESULTS SUMMARY




- Chart shows previous Shuttle risk estimates in red, with the Shuttle PRA being the most comprehensive PRA initiated by the Shuttle Program.
  - Earlier studies were not necessarily PRAs or had limited scope (e.g. Wiggins analysis was largely based upon expert opinion and Galileo Study was Ascent only)
- Around STS-114 the Shuttle Program started actively using the Shuttle PRA in program decisions

# ORBITER HARDWARE / SOFTWARE RESULTS SUMMARY




- There was an 50% likelihood of making it to flight 133 without LOCV due to Orbiter hardware/software

# CONCLUSIONS

- Using this analysis technique shows that Shuttle average mission risk has improved by approximately an order of magnitude over the life of the program
- Risk reductions are the result of re-designs or operational changes, the most significant of which follow major events (e.g. *Challenger*, *Columbia*, STS-27 TPS damage)
- This analysis is different than traditional reliability growth models which show improvement with each additional flight
  - Risk can increase due to trading safety margin for increased performance (e.g. SSME) or due to external events (e.g. EPA ban of CFC-11 Freon)
  - Significant improvement does not happen without time and money to re-design risk significant hardware (e.g. Block IIA SSME, IAPU) or without impacts to mission (e.g. ATL adjustments, inspections)
  - Need to understand what the drives the risk in order to reduce the risk (e.g. ascent debris)

# FUTURE WORK

- Quantify additional missions to fill in gaps starting with the following
  - **STS-107** *Columbia*
  - **STS-6** First 104% SSME flight
  - Additional flights to fill in gaps: **STS-41, STS-68 and STS-124**
- Consider including changing MMOD risk
  - MMOD was calculated starting at STS-50, however damage criteria has changed overtime making it difficult to assess consistently over time
- Provide additional risk progressions similar to Orbiter Hardware to show how various systems are changing over time

# BACKUP

# SHUTTLE PRA EVOLUTION

- Two of the earliest Shuttle risk assessments which are not included below are the “Wiggins Analysis” and the “Weatherwax Analysis”
  – The “Wiggins Analysis” conducted by the J. H. Wiggins Co. of Redondo Beach, Calif. between 1979 and 1982 put the overall risk of losing a shuttle between 1:1000 and 1:10000 and was mainly based upon engineering judgment
  – The “Weatherwax Analysis” prepared by R.K. Weatherwax of Sierra Energy and Risk Assessment Inc. in 1983 put the overall risk of losing a shuttle at ~1:35 was a review of the “Wiggins Analysis” with more of a data based approach
- The Shuttle PRA has been incrementally developed over many years
  - Mission Phases (Ascent, Orbit, Entry)
  - Number of Systems Modeled
  - Risk Factors considered (systems failures, phenomenological failures, human reliability, external events, etc.)
- The advent of established NASA requirements, standards, and tools - as well as the development of a strong shuttle program PRA team have resulted in significant recent progress

Mean Probability of LOCV

| Study | Mean Probability of LOCV | Description |
|---|---|---|
| Proof of concept Study 1987 | 1:70 | Proof of concept study for applying PRA to Space Shuttle. Scope was limited to APUs for Orbiter and SRB |
| Galileo 1988 | 1:55 | PRA analyzing launch risk of Galileo Mission with nuclear payload. (Ascent Only). |
| Phase 1 1993 | 1:73 | Update of the Galileo study results to reflect then current test and operational base of the Shuttle. (Ascent Only) |
| Shuttle PRA 1995 | 1:131 | Limited scope PRA combining ascent and entry /landing. Included only three Orbiter systems and the Propulsion elements . |
| Shuttle PRA 1998 | 1:234 | Unpublished analysis using QRAS. No integration of elements. Included only three Orbiter systems and the Propulsion elements. |
| SPRAT PRA Iteration 1.5 2003 | 1:78 | First full scope integrated Shuttle PRA with all elements, 18 Orbiter systems, MMOD and human actions included. Presented to OSMA peer review team. |
| *SPRAT PRA Iteration 2.0 2004/2005* | 1:61 | Updated SPRA Iteration 1.5 with initial incorporation of OSMA peer review comments. |
| *SPRAT PRA Iteration 2.1 2005* | 1:67 | Updated SSME pre-valve modeling |
| *SPRAT PRA Iteration 2.2 2006/2007* | 1:77 | Updated SPRA Iteration 2.1 with on-orbit TPS inspection with repair and crew rescue. Updated MMOD and ascent debris modeling |
| *SPRAT PRA Iteration 3.0 2008* | 1:81 | Updated SPRA Iteration 2.2 with abort modeling, rendezvous and docking. updated functional data, MMOD and ascent debris |
| *SPRAT PRA Iteration 3.1 2009* | 1:85 | Updated SPRA Iteration 3.0 with corrected APU hydrazine leak probabilities |
| *SPRAT PRA Iteration 3.2 2010* | 1:89 | Updated SPRA Iteration 3.1 with updated MMOD, ascent debris, Orbiter flight software, incorporated Orbiter review summit comments |
| *SPRAT PRA Iteration 3.3 2010* | 1:90 | 2011 Updated SPRA iteration 3.2 with corrected OMS/RCS fuel leak probabilities |

INCREASING FIDELITY AND EXPANDED SCOPE

# IMPACT OF ROGERS COMMISION RECOMMENDATIONS ON RISK

- SRM Re-design
  - Significantly reduced risk from ~1:25 to ~1:1500
- Impact of the Majority of the Recommendations are Difficult to Assess with PRA
  - Independent Oversight
  - Management Structure
  - Astronauts in Management
  - Shuttle Safety Panel
  - Criticality review of CILs and Hazard
  - Safety Organization
  - Improved Communication
  - Flight Rate
  - Maintenance Safeguards
- Landing Safety
  - From the Shuttle PRA perspective there was minimal impact to the overall risk
    - Especially the suggested improvements in Abort landing sites
    - Individual contributors may have improved by an order of magnitude (e.g. brakes going from 1E-4 to 1E-5) but were not risk drivers
- Launch Abort and Crew Escape
  - From the Shuttle PRA perspective improving 2 or 3 engine out capability does not impact the model since model assumes the loss of 2 or 3 engines is catastrophic and it is still not a risk driver
  - The Shuttle PRA does not include the Crew Escape System, from the Shuttle PRA perspective it is assumed if there is a fire/explosion there is LOCV, no credit is given to crew survivability

# IMPACT OF ROGERS COMMISION RECOMMENDATIONS ON RISK (2)

- Other Safety Considerations (not formal recommendations)
  - 17 inch disconnect valve exposure to inadvertent closure
    - Current Shuttle PRA does not give credit for addition of latch to 17 inch disconnect but valve transfers close is not a significant risk driver ~5.5E-6 since exposure time limited
  - ET vent valves indicate closed but valve is open
    - Valve was never re-designed but there was extensive analysis and testing to show that the risk is low. The PRA supports the determination that this was a low risk

# IMPACT OF CAIB RECOMMENDATIONS ON RISK

- Thermal Protection System
  - Risk reduced from ~1:130 to ~1:940, almost an order of magnitude after all the changes
    - ET Debris reduction
    - Orbiter hardening
    - Inspection
    - Repair
    - Crew Rescue
- Imaging
  - Relates to TPS risk reduction and MMOD risk reduction
- Orbiter Sensor Data
  - Relates to TPS risk reduction and MMOD risk reduction
- Test and Qualify Bolt Catchers
  - Relates to TPS risk reduction because it was a potential debris source
- Require Shuttle to have same level of Safety for MMOD as ISS and change guidelines to requirements
  - ATL adjustments significantly reduced the MMOD risk (~50%) however this risk reduction is not highlighted in the risk progression because risk is based upon STS-119 ATL
  - Risk reduced from ~1:190 to ~1:300 with late inspection implementation on STS-121

# IMPACT OF CAIB RECOMMENDATIONS ON RISK (2)

- Impact of the Majority of the Recommendations are Difficult to Assess with PRA
  - Wiring Inspections
  - Require at Least Two Employees Attend All Closeouts
  - Consistently define Foreign Object Debris (FOD) as FOD
  - Scheduling Pressure
  - MMT Training
  - Organization
  - Recertification
  - Closeout Photos / Drawing System

# MAJOR ASSUMPTIONS (STS-1)

- Crew Escape via ejection seats is modeled for STS-1
  - Ejection Seats are available for crew escape below ~80K feet which ~80 seconds on ascent and ~500 seconds on entry
  - Given a scenario that is assumed to be recoverable, ejection seats are given a 90% success rate (i.e. there is a 10% chance that either crewmember will not survive)
  - Scenarios which involve TPS failure (e.g. Ascent Debris, MMOD) are assumed not to be recoverable with ejection seats
  - Scenarios which occur on Orbit are assumed not to be recoverable with ejection seats.
- Solid Rocket Motor (SRM) risk based upon 1 LOCV in 25 missions
  - Mission specific risk is not modeled and it is assumed that LOCV could have occurred on any flight prior to when the re-designs were implemented (i.e. any previous mission could have had freezing temperatures)
- Orbiter flight software risk using Operational Increment 1 (OI-1) which flew on STS-7
  - This is the earliest estimate that is available, risk may be higher
- SSME risk based upon evaluation of First Manned Orbital Flight (FMOF) operational and testing history using SPRA methodology.
  - Credit given for SSME operating at 100% Rated Power Level (RPL)
- Ascent Debris tile risk based upon updated the ADAM model to sample from number of damages from STS-6 through STS-27
  - # of lower surface damages vary considerably making it difficult to fit a single distribution (7 hits to 272 hits)
  - Remaining ADAM distributions based upon the Pre-RTF distributions documented in the iteration 3.2 notebook
- Ascent Debris RCC risk is assumed to be 2.2 times the average RCC risk based upon the ratio of above calculated tile risk to average tile risk
- Orbiter APU risk includes catastrophic shaft seal failure and higher probability of hydrazine leakage leading to fire and explosion
- Bulk of data adjusted to remove any discounts of failures for both phenomenological leaks as well as functional failures

# MAJOR ASSUMPTIONS (STS-5)

- Crew Ejection Seats disabled, going from 2 to 4 crew
- SRM risk based upon 1 LOCV in 25 missions
- Orbiter flight software risk using OI-1
- Ascent Debris risk is the same as STS-1
  - Does not reduce until after STS-27
- Orbiter APU process improvements to reduce shaft seal fracture risk
  - Due to changes in hydrazine detection criteria
- Bulk of data adjusted to remove any discounts of failures that had not been “fixed” by STS-5

# MAJOR ASSUMPTIONS (STS-41B)

- SRM risk based upon 1 LOCV in 25 missions
- Orbiter flight software risk using OI-2
- SSME risk based upon evaluation of Full Power Level (FPL) operational and test history using SPRA methodology
- Ascent Debris risk is the same as STS-1
  - Does not reduce until after STS-27
- Orbiter APU Hydrazine leakage reduced due to processing improvements following STS-9
- Bulk of data adjusted to remove any discounts of failures that had not been “fixed” by STS-41B

# MAJOR ASSUMPTIONS (STS-51L)

- SRM risk based upon 1 LOCV in 25 missions
- Orbiter flight software risk using OI-7
- SSME risk based upon evaluation of Full Power Level (FPL) operational and test history using SPRA methodology
- Ascent Debris risk is the same as STS-1
  - Does not reduce until after STS-27
- Orbiter APU Hydrazine leakage reduced due to re-design of injector
- Bulk of data adjusted to remove any discounts of failures that had not been “fixed” by STS-51L

# MAJOR ASSUMPTIONS (STS-26)

- Reusable Solid Rocket Motor (RSRM) risk based upon SPRA iteration 3.3
- SSME risk based upon evaluation of Phase II operational and test history using SPRA methodology
- Ascent Debris risk is the same as STS-1
  - Does not reduce until after STS-27
- Orbiter APU Hydrazine leakage reduced due to re-design of injector
- Orbiter flight software risk using OI-8B
- Bulk of data adjusted to remove any discounts of failures that had not been “fixed” by STS-26

# MAJOR ASSUMPTIONS (STS-29)

- RSRM risk based upon SPRA iteration 3.3
- SSME risk based upon evaluation of Phase II operational and test history using SPRA methodology
- Ascent Debris tile risk based upon re-fitting ADAM input distributions based upon damages on STS-28 through STS-85 and running model with no repair
  - Risk is lower because of "fixes" following STS-27
    - MSA-1 ablative material had a flatwise tensile strength of 50 PSI; this was deemed inadequate.
    - The ablative material was changed to MSA-2 with an flatwise tensile strength of 75 PSI for STS-29 and subs
- Ascent Debris RCC risk is assumed to be 0.55 times the average RCC risk based upon the ratio of above calculated tile risk to average tile risk
- Orbiter flight software risk using OI-8B
- Bulk of data adjusted to remove any discounts of failures that had not been "fixed" by STS-29

# MAJOR ASSUMPTIONS (STS-49)

- RSRM risk based upon SPRA iteration 3.3
- SSME risk based upon evaluation of Phase II operational and test history using SPRA methodology
- Ascent Debris risk is the same as STS-29
- Orbiter flight software risk using OI-21
- APU risk based upon IAPU
- Bulk of data adjusted to remove any discounts of failures that had not been “fixed” by STS-49

# MAJOR ASSUMPTIONS (STS-77)

- RSRM risk based upon SPRA iteration 3.3
- SSME risk based upon evaluation of Block I and Block IA operational and test history using SPRA methodology
- Ascent Debris risk is the same as STS-29
- Orbiter flight software risk using OI-24
- Bulk of data adjusted to remove any discounts of failures that had not been "fixed" by STS-77

# MAJOR ASSUMPTIONS (STS-86)

- RSRM risk based upon SPRA iteration 3.3
- SSME risk based upon evaluation of Block I and Block IA operational and test history using SPRA methodology
- Ascent Debris tile risk based upon using frequency of damages on STS-86 through STS-93 input into ADAM, other inputs are based upon the Pre-RTF distributions documented in the iteration 3.2 notebook with no repair
  - Dimensions and location of damages are unavailable for STS-86 which had the most significant damage
  - Risk is significantly higher because of new foam application process implemented on STS-86
- Ascent Debris RCC risk is assumed to be 1.7 times the average RCC risk based upon the ratio of above calculated tile risk to average tile risk
- Orbiter flight software risk using OI-26
- Bulk of data adjusted to remove any discounts of failures that had not been “fixed” by STS-86

# MAJOR ASSUMPTIONS (STS-89)

- RSRM risk based upon SPRA iteration 3.3
- SSME risk based upon evaluation of Block IIA operational and test history using SPRA methodology
- Ascent Debris risk is the same as STS-86
- Orbiter flight software risk using OI-26
- Bulk of data adjusted to remove any discounts of failures that had not been “fixed” by STS-89

# MAJOR ASSUMPTIONS (STS-103)

- RSRM risk based upon SPRA iteration 3.3
- SSME risk based upon evaluation of Block IIA operational and test history using SPRA methodology
- Ascent Debris tile risk based upon re-fitting ADAM input distributions based upon damages on STS-103 through STS-114 and running model with no repair
  - Risk is lower because of implementation of ET TPS venting holes on STS-103 (risk goes down to just below where it was before EPA banned CFC-11 Freon)
- Ascent Debris RCC risk is assumed to be 0.39 times the average RCC risk based upon the ratio of above calculated tile risk to average tile risk
- Orbiter flight software risk using OI-26B
- Bulk of data adjusted to remove any discounts of failures that had not been “fixed” by STS-103

# MAJOR ASSUMPTIONS (STS-110)

- RSRM risk based upon SPRA iteration 3.3
- SSME risk based upon evaluation of Block II operational and test history using SPRA methodology.
- Ascent Debris risk is the same as STS-103
- Orbiter flight software risk using OI-29
- Bulk of data adjusted to remove any discounts of failures that had not been "fixed" by STS-110

# ASSUMPTIONS (STS-114)

- RSRM risk based upon SPRA iteration 3.3
- SSME risk based upon evaluation of Block II operational and test history using SPRA methodology.
- Ascent Debris risk is the same as STS-110 except that it includes inspection and repair
  - Inspection and repair based upon SPRA iteration 2.2
- MMOD includes a FD2 inspection but no late inspection
  - No IDC for nose cap therefore assumed to be equivalent to LDRI of WLE RCC.
- Orbiter flight software risk using OI-30
- Risk due to BSM debris is reduced due to process improvements
- Bulk of data adjusted to remove any discounts of failures that had not been “fixed” by STS-114

# ASSUMPTIONS (STS-133)

- Risk equivalent to SPRA iteration 3.3
  - SSME risk includes risk reduction due to Advanced Health Monitoring System (AHMS)
  - MMOD now includes late inspection
  - Repair and inspection estimates improved over STS-114 estimates

# STS-1 RESULTS

## (5th 1:23, **Mean 1:12**, 95th 1:7)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description |
|---|---|---|---|---|
| 1 | 53.5 | 53.5 | 4.5E-02 (1:22) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry |
| 2 | 19.2 | 72.8 | 1.6E-02 (1:63) | Solid Rocket Motor (SRM)-induced SRM catastrophic failure and ejection seats fail to save the crew |
| 3 | 6.4 | 79.2 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry |
| 4 | 5.0 | 84.2 | 4.2E-03 (1:240) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure and ejection seats fail to save the crew |
| 5 | 3.7 | 87.9 | 3.1E-03 (1:320) | Orbiter APU Shaft Seal Fracture Entry and ejection seats fail to save the crew |
| 6 | 2.9 | 90.8 | 2.4E-03 (1:420) | Auxiliary Power Unit (APU) external leak on entry and ejection seats fail to save the crew |
| 7 | 2.0 | 92.8 | 1.7E-03 (1:600) | Orbiter flight software error results in catastrophic failure during ascent and ejection seats fail to save the crew |
| 8 | 1.1 | 93.9 | 9.0E-04 (1:1100) | APU external leak on ascent and ejection seats fail to save the crew |
| 9 | 1.1 | 95.0 | 8.8E-04 (1:1100) | Orbiter APU Shaft Seal Fracture Ascent and ejection seats fail to save the crew |
| 10 | 0.8 | 95.7 | 6.3E-04 (1:1600) | SSME-induced benign shutdown of the SSME and ejection seats fail to save the crew |

- STS-1 Risk driven by Ascent Debris and SRM risk
- Ejection Seats reduce risk from 1:9 to 1:12 (22% reduction)

# STS-5 RESULTS

## (5th 1:20, **Mean 1:10**, 95th 1:5)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description | Delta Risk from STS-1 |
|---|---|---|---|---|---|
| 1 | 42.5 | 42.5 | 4.5E-02 (1:22) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry | None |
| 2 | 38.2 | 80.7 | 4.0E-02 (1:25) | Solid Rocket Motor (SRM)-induced SRM catastrophic failure | ↑1:42 |
| 3 | 5.1 | 85.8 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry | None |
| 4 | 4.6 | 90.5 | 4.9E-03 (1:210) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure | ↑1:1500 |
| 5 | 2.5 | 93.0 | 2.6E-03 (1:380) | Auxiliary Power Unit (APU) external leak on entry | ↑1:4500 |
| 6 | 1.7 | 94.7 | 1.8E-03 (1:560) | Orbiter flight software error results in catastrophic failure during ascent | ↑1:7000 |
| 7 | 1.6 | 96.3 | 1.7E-03 (1:590) | Orbiter APU Shaft Seal Fracture Entry | ↓1:710 |
| 8 | 0.9 | 97.3 | 9.8E-04 (1:1000) | APU external leak on ascent | ↑1:13000 |
| 9 | 0.8 | 98.0 | 8.2E-04 (1:1200) | Crew error during entry | ↑1:3400 |
| 10 | 0.7 | 98.7 | 7.1E-04 (1:1400) | SSME-induced benign shutdown of the SSME | ↑1:14000 |

- Ejection Seats disabled, most of the top risks increase
- APU shaft seal fracture risk decreases changes in hydrazine detection criteria

# STS-41B RESULTS

## ($5^{th}$ 1:22, **Mean 1:10**, $95^{th}$ 1:5)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description | Delta Risk from STS-5 |
|---|---|---|---|---|---|
| 1 | 43.6 | 43.6 | 4.5E-02 (1:22) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry | None |
| 2 | 39.1 | 82.7 | 4.0E-02 (1:25) | Solid Rocket Motor (SRM)-induced SRM catastrophic failure | None |
| 3 | 5.7 | 88.4 | 5.9E-03 (1:170) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure | ↑1:1000 |
| 4 | 5.2 | 93.7 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry | None |
| 5 | 0.7 | 94.4 | 1.7E-03 (1:590) | Orbiter APU Shaft Seal Fracture Entry | None |
| 6 | 1.7 | 96.0 | 1.7E-03 (1:600) | Orbiter flight software error results in catastrophic failure during ascent | ↓1:7700 |
| 7 | 1.6 | 97.7 | 8.2E-04 (1:1200) | Crew error during entry | None |
| 8 | 0.8 | 98.5 | 7.2E-04 (1:1400) | SSME-induced benign shutdown of the SSME | ↑1:110000 |
| 9 | 0.5 | 98.9 | 4.8E-04 (1:2100) | Orbiter APU Shaft Seal Fracture Ascent | None |
| 10 | 0.5 | 99.4 | 4.7E-04 (1:2100) | Fuel supply failure to the OMS during orbit | None |

- SSME risk increased due to additional test failures of the FPL engine that are due in part to a higher operational power level
- Orbiter flight software risk decreases due to use of OI-2 vs. OI-1
- APU external leak risk decreases and drops from top 10 due to process improvements after STS-9 APU fire (full re-design not in place)

# STS-51L RESULTS

## ($5^{th}$ 1:23, **Mean 1:10**, $95^{th}$ 1:5)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description | Delta Risk from STS-41B |
|---|---|---|---|---|---|
| 1 | 45.0 | 45.0 | 4.5E-02 (1:22) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry | None |
| 2 | 40.4 | 85.4 | 4.0E-02 (1:25) | Solid Rocket Motor (SRM)-induced SRM catastrophic failure | None |
| 3 | 5.4 | 90.8 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry | None |
| 4 | 5.2 | 96.1 | 5.2E-03 (1:190) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure | ↓1:1500 |
| 5 | 1.1 | 97.1 | 1.1E-03 (1:950) | Orbiter flight software error results in catastrophic failure during ascent | ↓1:1600 |
| 6 | 0.8 | 98.0 | 8.2E-03 (1:1200) | Crew error during entry | None |
| 7 | 0.6 | 98.5 | 5.5E-04 (1:1800) | SSME-induced benign shutdown of the SSME | ↓1:6100 |
| 8 | 0.5 | 99.0 | 4.7E-04 (1:2100) | Fuel supply failure to the OMS during orbit | None |
| 9 | 0.4 | 99.4 | 3.7E-04 (1:2700) | Debonding of TPS during ascent | None |
| 10 | 0.3 | 99.7 | 3.4E-04 (1:2900) | Orbiter APU Shaft Seal Fracture Entry | ↓1:730 |

- STS-51L Risk equally driven by SRM and Ascent Debris risk
- Risk reduction in SSME due to improvements in FPL engine
- Orbiter APU risk on ascent dropped from the top 10 due to re-design post STS-9
- Risk reduction in Orbiter flight software (OI-7 vs. OI-1)

# STS-26 RESULTS

## (5th 1:36, **Mean 1:17**, 95th 1:8)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description | Delta Risk from STS-51L |
|---|---|---|---|---|---|
| 1 | 73.7 | 73.7 | 4.5E-02 (1:22) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry | None |
| 2 | 8.8 | 82.5 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry | None |
| 3 | 5.6 | 88.1 | 3.4E-03 (1:290) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure | ↓1:560 |
| 4 | 1.4 | 89.4 | 8.2E-04 (1:1200) | Crew error during entry | None |
| 5 | 1.3 | 90.7 | 7.6E-04 (1:1300) | Orbiter flight software error results in catastrophic failure during ascent | ↓1:3400 |
| 6 | 1.1 | 91.8 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure | ↓1:25 |
| 7 | 0.8 | 92.5 | 4.7E-04 (1:2100) | Fuel supply failure to the OMS during orbit | None |
| 8 | 0.6 | 93.2 | 3.7E-04 (1:2700) | Debonding of TPS during ascent | None |
| 9 | 0.6 | 93.7 | 3.4E-04 (1:2900) | Orbiter APU Shaft Seal Fracture Entry | None |
| 10 | 0.4 | 94.2 | 2.6E-04 (1:3800) | SSME-induced benign shutdown of the SSME | ↓1:3400 |

- RSRM risk decreased due to re-design post *Challenger*
- SSME Risk decreased due to risk reduction with Phase II engine
- Risk reduction in Orbiter flight software (OI-8B vs. OI-7)

# STS-29 RESULTS

## (5th 1:57, **Mean 1:35**, 95th 1:23)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description | Delta Risk from STS-26 |
|---|---|---|---|---|---|
| 1 | 40.2 | 40.2 | 1.1E-02 (1:89) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry | ↓1:35 |
| 2 | 19.1 | 59.3 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry | None |
| 3 | 12.2 | 71.5 | 3.4E-03 (1:290) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure | None |
| 4 | 2.9 | 74.4 | 8.2E-04 (1:1200) | Crew error during entry | None |
| 5 | 2.7 | 77.1 | 7.6E-04 (1:1300) | Orbiter flight software error results in catastrophic failure during ascent | None |
| 6 | 2.3 | 79.5 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure | None |
| 7 | 1.6 | 81.1 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit | ↓1:41000 |
| 8 | 1.3 | 82.4 | 3.7E-04 (1:2700) | Debonding of TPS during ascent | None |
| 9 | 1.2 | 83.6 | 3.4E-04 (1:2900) | Orbiter APU Shaft Seal Fracture Entry | None |
| 10 | 0.8 | 84.5 | 2.3E-04 (1:4300) | SRB booster separation motor debris strikes Orbiter windows | None |

- Ascent Debris risk significantly drops due to lower likelihood of having damage >100, post STS-27.
- OMS fuel supply risk decreases slightly due to He Regulator changes

# STS-49 RESULTS

## (5th 1:60, **Mean 1:37**, 95th 1:23)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description | Delta Risk from STS-29 |
|---|---|---|---|---|---|
| 1 | 41.4 | 41.4 | 1.1E-02 (1:89) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry | None |
| 2 | 19.7 | 61.1 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry | None |
| 3 | 12.5 | 73.6 | 3.4E-03 (1:290) | Space Shuttle Main Engine (SSME)-induced SSME uncontained failure | None |
| 4 | 3.0 | 76.6 | 8.2E-04 (1:1200) | Crew error during entry | None |
| 5 | 2.4 | 79.0 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure | None |
| 6 | 1.8 | 80.9 | 5.0E-04 (1:2000) | Orbiter flight software error results in catastrophic failure during ascent | ↓1:3900 |
| 7 | 1.7 | 82.5 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit | None |
| 8 | 1.4 | 83.9 | 3.7E-04 (1:2700) | Debonding of TPS during ascent | None |
| 9 | 0.9 | 84.7 | 2.3E-04 (1:4300) | SRB booster separation motor debris strikes Orbiter windows | None |
| 10 | 0.7 | 85.4 | 1.8E-04 (1:5500) | Mechanisms failure | None |

- Risk is very similar to STS-29 with a risk reduction in Orbiter flight software (OI-21 vs. OI-8B) and Risk reductions due to IAPU

# STS-77 RESULTS

## (5th 1:62, **Mean 1:38**, 95th 1:24)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description | Delta Risk from STS-49 |
|---|---|---|---|---|---|
| 1 | 42.8 | 42.8 | 1.1E-02 (1:89) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry | None |
| 2 | 20.4 | 63.2 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry | None |
| 3 | 10.2 | 73.4 | 2.7E-03 (1:380) | Space Shuttle Main Engine (SSME)-induced SSME uncontained failure | ↓1:1400 |
| 4 | 3.1 | 76.6 | 8.2E-04 (1:1200) | Crew error during entry | None |
| 5 | 2.5 | 79.1 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure | None |
| 6 | 1.7 | 80.8 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit | None |
| 7 | 1.5 | 82.2 | 3.8E-04 (1:2600) | Orbiter flight software error results in catastrophic failure during ascent | ↓1:8500 |
| 8 | 1.4 | 83.7 | 3.7E-04 (1:2700) | Debonding of TPS during ascent | None |
| 9 | 0.9 | 84.5 | 2.3E-04 (1:4300) | SRB booster separation motor debris strikes Orbiter windows | None |
| 10 | 0.7 | 85.2 | 1.8E-04 (1:5500) | Mechanisms failure | None |

- SSME risk reduction due to Block I and IA vs. Phase II engine
- Risk reduction in Orbiter flight software (OI-24 vs. OI-21)

# STS-86 RESULTS

## (5th 1:44, Mean 1:21, 95th 1:11)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description | Delta Risk from STS-77 |
|---|---|---|---|---|---|
| 1 | 70.8 | 70.8 | 3.4E-02 (1:30) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry | ↑1:44 |
| 2 | 11.1 | 81.9 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry | None |
| 3 | 5.6 | 87.5 | 2.7E-03 (1:380) | Space Shuttle Main Engine (SSME)-induced SSME uncontained failure | None |
| 4 | 1.7 | 89.2 | 8.2E-04 (1:1200) | Crew error during entry | None |
| 5 | 1.4 | 90.6 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure | None |
| 6 | 0.9 | 91.5 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit | None |
| 7 | 0.8 | 92.3 | 3.7E-04 (1:2700) | Debonding of TPS during ascent | None |
| 8 | 0.7 | 92.9 | 3.2E-04 (1:3100) | Orbiter flight software error results in catastrophic failure during ascent | ↓1:15000 |
| 9 | 0.5 | 93.4 | 2.3E-04 (1:4300) | SRB booster separation motor debris strikes Orbiter windows | None |
| 10 | 0.4 | 93.8 | 1.9E-04 (1:5400) | SSME-induced benign shutdown of the SSME | ↑1:22000 |

- Ascent Debris risk increase due to revised ET foam application process
- SSME shutdown risk increase due to Ascent Debris risk increase
- Risk reduction in Orbiter flight software (OI-26 vs. OI-24)

# STS-89 RESULTS

## (5th 1:46, **Mean 1:21**, 95th 1:11)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description | Delta Risk from STS-86 |
|---|---|---|---|---|---|
| 1 | 72.6 | 72.6 | 3.4E-02 (1:30) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry | None |
| 2 | 11.4 | 84.0 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry | None |
| 3 | 3.1 | 87.2 | 1.5E-03 (1:680) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure | ↓1:840 |
| 4 | 1.8 | 88.9 | 8.2E-04 (1:1200) | Crew error during entry | None |
| 5 | 1.4 | 90.3 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure | None |
| 6 | 1.0 | 91.3 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit | None |
| 7 | 0.8 | 92.1 | 3.7E-04 (1:2700) | Debonding of TPS during ascent | None |
| 8 | 0.7 | 92.8 | 3.2E-04 (1:3100) | Orbiter flight software error results in catastrophic failure during ascent | None |
| 9 | 0.5 | 93.2 | 2.3E-04 (1:4300) | SRB booster separation motor debris strikes Orbiter windows | None |
| 10 | 0.4 | 93.6 | 1.8E-04 (1:5500) | Mechanisms failure | None |

- SSME risk reduction due to Block IIA vs. Block I engine

# STS-103 RESULTS

## (5th 1:74, Mean 1:47, 95th 1:31)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description | Delta Risk from STS-89 |
|---|---|---|---|---|---|
| 1 | 37.3 | 37.3 | 7.9E-03 (1:130) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry | ↓1:38 |
| 2 | 25.2 | 62.5 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry | None |
| 3 | 6.9 | 69.5 | 1.5E-03 (1:680) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure | None |
| 4 | 3.9 | 73.3 | 8.2E-04 (1:1200) | Crew error during entry | None |
| 5 | 3.1 | 76.4 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure | None |
| 6 | 2.1 | 78.6 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit | None |
| 7 | 1.7 | 80.3 | 3.7E-04 (1:2700) | Debonding of TPS during ascent | None |
| 8 | 1.4 | 81.7 | 3.0E-04 (1:3400) | Orbiter flight software error results in catastrophic failure during ascent | ↓1:48000 |
| 9 | 1.1 | 82.8 | 2.3E-04 (1:4300) | SRB booster separation motor debris strikes Orbiter windows | None |
| 10 | 0.9 | 83.7 | 1.8E-04 (1:5500) | Mechanisms failure | None |

- Ascent Debris risk significantly decreases due to ET foam venting holes on STS-103
- Risk reduction in Orbiter flight software (OI-26 vs. OI-26B)

# STS-110 RESULTS

## (5th 1:74, Mean 1:47, 95th 1:31)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description | Delta Risk from STS-103 |
|---|---|---|---|---|---|
| 1 | 37.4 | 37.4 | 7.9E-03 (1:130) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry | None |
| 2 | 25.3 | 62.7 | 5.3E-03 (1:190) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry | None |
| 3 | 7.8 | 70.5 | 1.6E-03 (1:610) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure | ↑1:5600 |
| 4 | 3.9 | 74.4 | 8.2E-04 (1:1200) | Crew error during entry | None |
| 5 | 3.1 | 77.5 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure | None |
| 6 | 2.1 | 79.6 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS | None |
| 7 | 1.7 | 81.3 | 3.7E-04 (1:2700) | Debonding of TPS during ascent | None |
| 8 | 1.2 | 82.6 | 2.6E-04 (1:3800) | Orbiter flight software error results in catastrophic failure during ascent | ↓1:27000 |
| 9 | 0.9 | 83.4 | 1.8E-04 (1:5500) | Mechanisms failure | None |
| 10 | 0.8 | 84.3 | 1.8E-04 (1:5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling | None |

- SSME risk increases due to engine re-design (Block II vs. Block IIA engine)
  - There were three early HPFTP-AT related failures. Although heavily discounted due to improvements, risk still increases.
- Risk reduction in Orbiter flight software (OI-29 vs. OI-26)

# STS-114 RESULTS

## (5th 1:100, **Mean 1:73**, 95th 1:52)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description | Delta Risk from STS-110 |
|---|---|---|---|---|---|
| 1 | 37.3 | 37.3 | 5.1E-03 (1:200) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry | ↓1:4700 |
| 2 | 12.1 | 49.4 | 1.7E-03 (1:600) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry | ↓1:160 |
| 3 | 12.0 | 61.4 | 1.6E-03 (1:610) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure | None |
| 4 | 6.0 | 67.3 | 8.2E-04 (1:1200) | Crew error during entry | None |
| 5 | 4.8 | 72.1 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure | None |
| 6 | 1.6 | 73.8 | 2.3E-04 (1:4400) | Orbiter flight software error results in catastrophic failure during ascent | ↓1:29000 |
| 7 | 1.3 | 75.1 | 1.8E-04 (1:5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling | None |
| 8 | 1.2 | 76.3 | 1.7E-04 (1:5900) | Solid Rocket Booster (SRB) APU shaft seal fracture | None |
| 9 | 1.1 | 77.4 | 1.5E-04 (1:6500) | SRB booster separation motor debris strikes Orbiter windows | None |
| 10 | 1.0 | 78.4 | 1.3E-04 (1:7600) | Flow Control Valve (FCV) poppet failure causes rupture in the GH2 re-pressurization line | None |

- Ascent Debris risk significantly drops due to inspection with repair and crew rescue. No credit given to reduced environment.
- MMOD risk slightly decreases due to FD2 inspection (no late inspection)

# STS-133 RESULTS (ITERATION 3.3 with updated SSME)

## (5th 1:130, Mean 1:90, 95th 1:63)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description | Delta Risk from STS-114 |
|---|---|---|---|---|---|
| 1 | 29.6 | 29.6 | 3.3E-03 (1:300) | Micrometeoroid and Orbital Debris (MMOD) strikes Orbiter on orbit leading to LOCV on orbit or entry | ↓1:550 |
| 2 | 13.7 | 43.3 | 1.5E-03 (1:650) | Space Shuttle Main Engine (SSME)-induced SSME catastrophic failure | ↓1:8500 |
| 3 | 9.6 | 52.9 | 1.1E-03 (1:940) | Ascent debris strikes Orbiter Thermal Protection System (TPS) leading to LOCV on orbit or entry | ↓1:1700 |
| 4 | 7.4 | 60.3 | 8.2E-04 (1:1200) | Crew error during entry | None |
| 5 | 5.9 | 66.1 | 6.5E-04 (1:1500) | Reusable Solid Rocket Motor (RSRM)-induced RSRM catastrophic failure | None |
| 6 | 2.0 | 68.2 | 2.3E-04 (1:4400) | Flight Software error result in catastrophic failure during ascent | None |
| 7 | 1.6 | 69.8 | 1.8E-04 (1:5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling | None |
| 8 | 1.5 | 71.3 | 1.7E-04 (1:5900) | Solid Rocket Booster (SRB) APU shaft seal fracture | None |
| 9 | 1.2 | 72.5 | 1.3E-04 (1:7600) | Flow Control Valve (FCV) poppet failure causes rupture in the GH2 re-pressurization line | None |
| 10 | 1.2 | 73.6 | 1.3E-04 (1:7700) | Collision of the Orbiter with the International Space Station (ISS) during rendezvous and docking | None |

- MMOD risk decreases due to late inspection
- Ascent Debris risk decrease due to reduced debris environment and improved repair
- SSME risk decreases due to AHMS

# DATA DEVELOPMENT

- RSRM
  - Reusable Solid Rocket Motor (SRM) risk based upon 1 LOCV in 25 missions prior to *Challenger* and based upon iteration 3.3 for the remaining missions
- Functional Data
  - A modified version of the SPRA functional database was created which enables the user to select a particular flight and the failure rate/probability will be updated to be used in the SAPHIRE input file (.bei file)
    - All Bayesian updated data was reviewed and discounts taken for design changes were evaluated for when they were implemented and separate failure rates/probabilities were calculated based upon removing the discounts
      - For example Orbiter Auxiliary Power Unit (APU) failure to run is automatically assigned a failure rate of 4.36E-3/hr if STS-1 is selected and 1.76E-3/hr if STS-133 is selected because of failures on STS-7 and STS-71 which had design changes implemented by STS-133.
    - Unique data events such as tires and icicles forming during water dumps were evaluated separately and flight effectivities were assigned
- Phenomenological Data
  - Discounts were removed based upon when design changes were implemented and Shuttle Phenomenological Leak Analysis Tool (SPLAT) was used to calculate update results
    - Since SPLAT takes some time to run only evaluated specific missions of interest
    - For example the probability of Orbiter APU High Pressure Hydrazine leakage for STS-1 is 3.6E-03/mission and for STS-133 it is 1.64E-04/mission

# DATA DEVELOPMENT (2)

- Space Shuttle Main Engine (SSME) Uncontained Data
  - First Manned Orbital Flight (FMOF), STS-1 through STS-5
    - Partial failure discount given for FMOF engines operating at much lower rated power level (RPL) than tests failures, fleet leaders ground test failure and chance of material defects on flight engines
  - Full Power Level (FPL), STS-6 to STS-41B
    - Most of the engine failures occurred prior and during FPL flight were addressed by STS-41B
    - Minimal discounts applied to high pressure turbopump bearing sub synchronous vibration based on understanding of the failure mode, and that the redesign is not implemented until Phase II
  - Full Power Level (FPL), STS-41B through STS-51L
    - Slight improvement in risk due to the addition of HPFTP coolant liner pressure redline on STS-41C, and life limits on HPFTP first stage impeller
  - Phase II, STS-26 through STS-76 plus STS-94
    - Risk significantly reduced due to the redesign HPFTP coolant liner seals, HPFTP first stage impeller manufacturing changes, and life limits on MCC and nozzle
    - STS-94 is considered Phase II even though it has one Block IA
  - Block I, STS-77through STS-88
    - Included risks for Block IA configuration, and a handful of Phase II engines flights
    - Risk is reduced due to the introduction of HPOTP-AT, and the only applicable HPOTP-AT failure was corrected by first Block I flight
    - Additional risk reduction from HPOTP-AT hardware robustness factor was mistakenly left out, but the difference is not significant
  - Block IIA, STS-89 to STS-109
    - Significant risk reduction due to the incorporation of the Large Throat Main Combustion Chamber (LTMCC) and associated Block II environment factor for reduced harsh operating environment introduced by LTMCC
    - Additional risk reduction from HPFTP-AT hardware robustness factor was mistakenly left out, but the difference is not significant
  - Block II w/o Advanced Health Management System (AHMS), STS-110 to STS-118
    - Slight increase in risk over Block IIA engine due to addition of three early HPFTP-AT related failures that were heavily discounted
  - Block II w/ AHMS, STS-118 to Today
    - Two of the HPFTP-AT uncontained failures that could be caught by AHMS were transfer to safe shutdown category

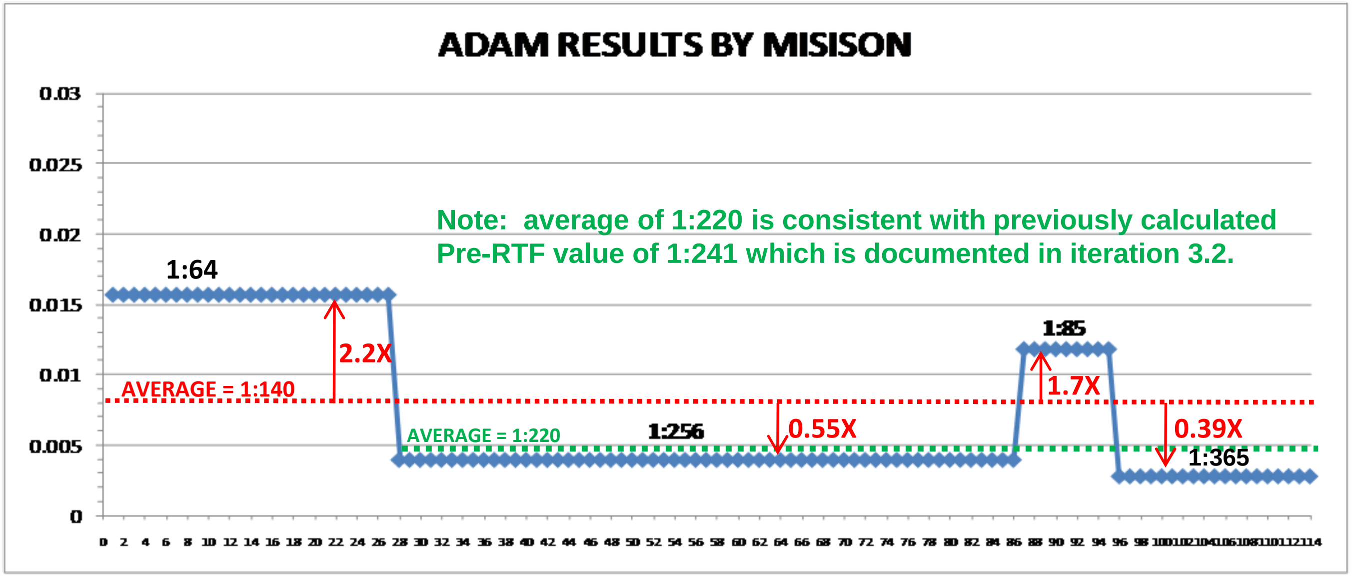
# DATA DEVELOPMENT (3)

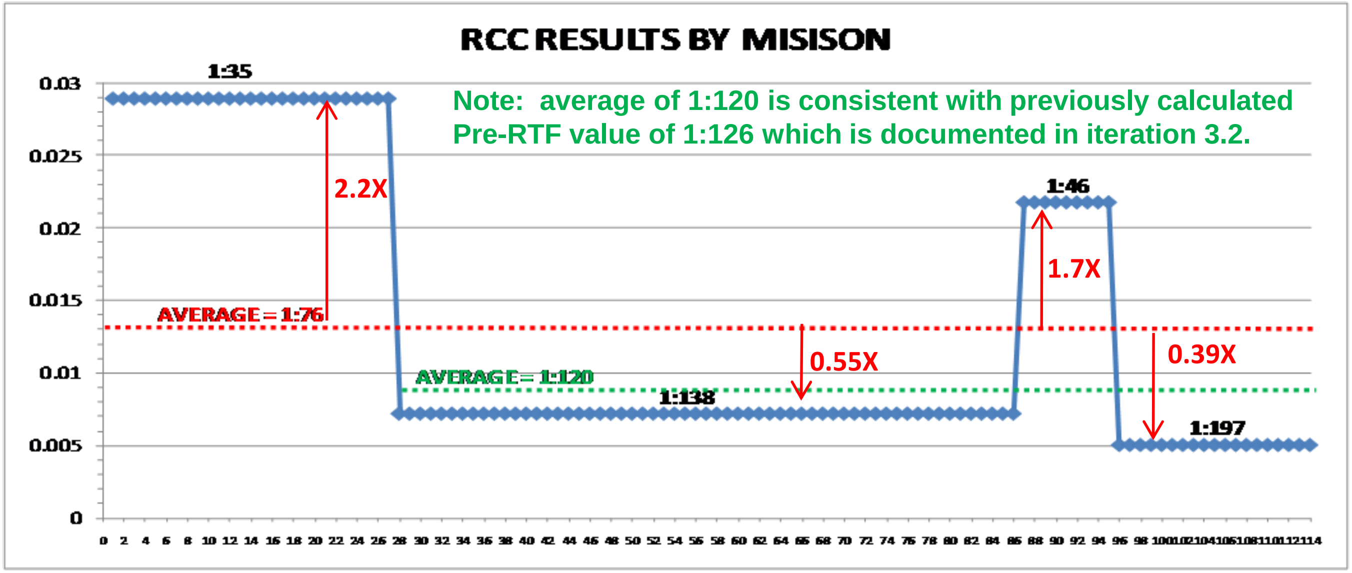
- Space Shuttle Main Engine (SSME) Safe Shutdown Data
  - First Manned Orbital Flight (FMOF), STS-1 through STS-5
    - Corrective actions for two failures were implemented by STS-1
    - Partial failure discount given for FMOF engines operating at 100% rated power level (RPL) where the failures happened at higher RPL or chance of material defects on flight engines
    - Other future failures were not discounted if they were deemed possible
  - Full Power Level (FPL), STS-6 to STS-41B
    - Partial failure discount given for portion of the FPL engines that did not get redesign and corrective actions, and failure occurring at much higher ground tests power level
  - Full Power Level (FPL), STS-41B through STS-51L
    - Majority of the SSME safe shutdown occurred and corrective action completed prior to STS-51L
    - STS-51F temp sensor failure and flowmeter parameter loading error were not discounted
  - Phase II, STS-26 through STS-76 plus STS-94
    - Majority of the SSME safe shutdown occurred and corrective action implemented by phase II engine
  - Block I, STS-77through STS-88
    - Included risks for Block IA configuration, and a handful of full cluster Phase II engines flights
    - Risk is reduced due to introduction of HPOTP-AT,
    - Additional risk reduction from HPOTP-AT hardware robustness factor was mistakenly left out, but the difference is not significant
  - Block IIA, STS-89 to STS-109
    - Significant risk reduction due to the incorporation of the Large Throat Main Combustion Chamber (LTMCC) and associated Block II environment factor for reduced harsh environment introduced by LTMCC
    - There were no applicable HPFTP-AT or HPOTP-AT failures counted against Block I through Block II without AHMS engines
    - Additional risk reduction from HPFTP-AT hardware robustness factor was mistakenly left out, but the difference is not significant
  - Block II w/o Advanced Health Management System (AHMS), STS-110 to STS-118
    - No change in risk from Block IIA due to no applicable failures
  - Block II w/ AHMS, STS-118 to Today
    - Two of the HPFTP-AT uncontained failures that could be caught by AHMS were transfer to safe shutdown category

# DATA DEVELOPMENT (4)

- Ascent Debris
  - Tile risk is based upon Orbiter damages and uses the ADAM model and RCC risk is based upon flight history using engineering judgment to adjust with the changing environment. The chart on the next pages provides additional detail on how the RCC risk is adjusted.
- Inspection
  - Prior to STS-114 no inspection
  - STS-114 FD2 inspection but no late inspection
  - Post STS-114 FD2 and late inspection
- Repair
  - Prior to STS-114 no repair
  - STS-114 limited repair capability with large uncertainties (SPRA iteration 2.2 values)
  - Post STS-114 repair capability the same as iteration 3.3

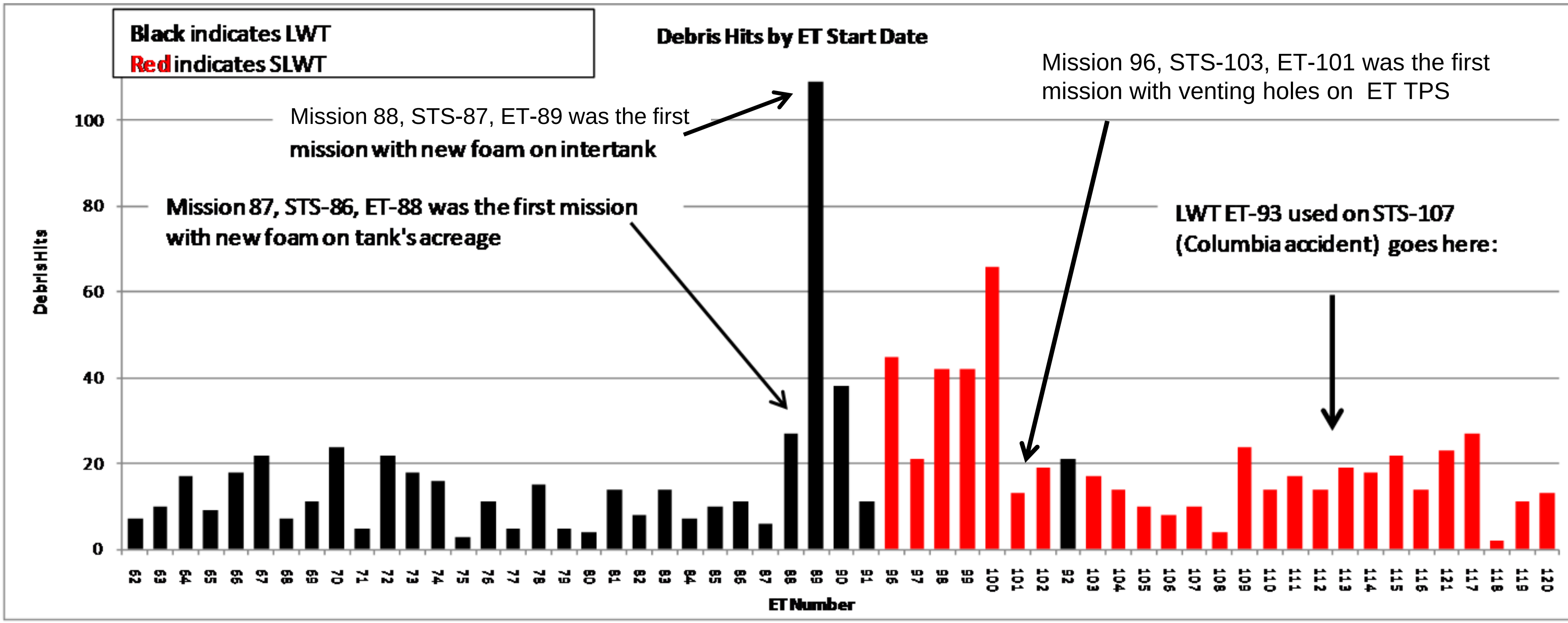
# DATA DEVELOPMENT ASCENT DEBRIS RISK



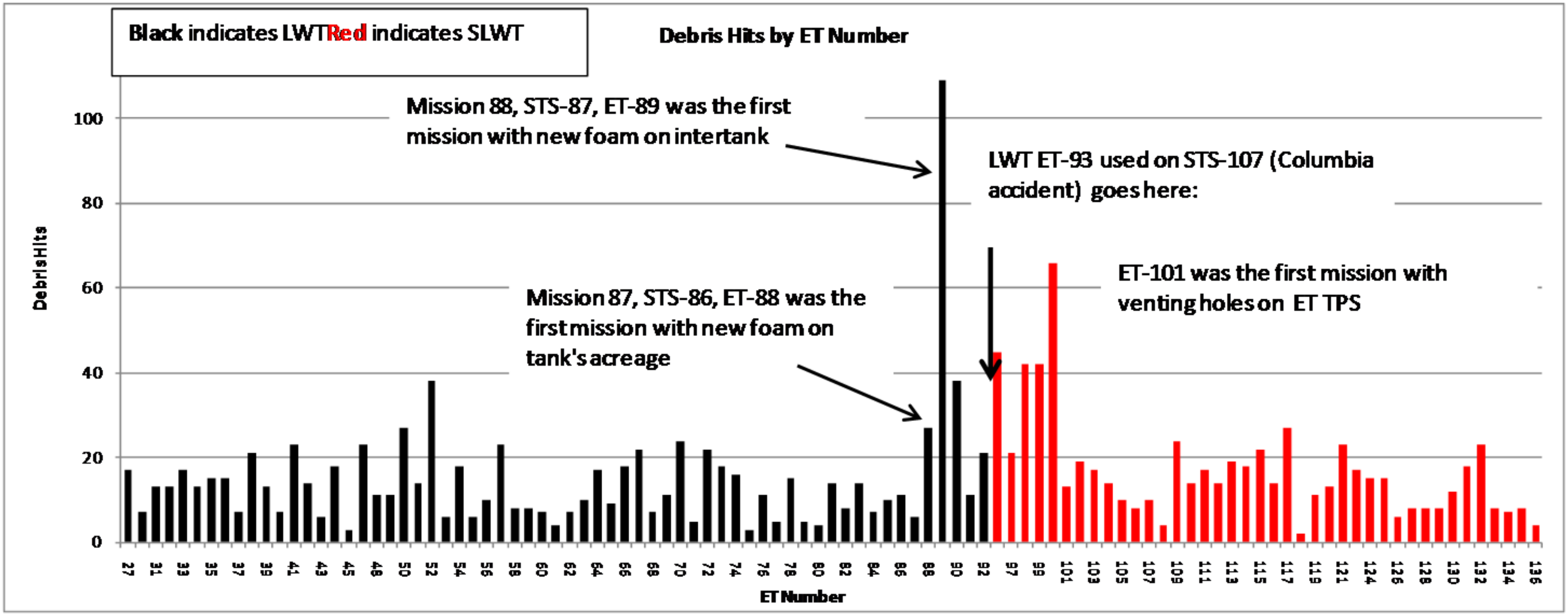

RCC is assumed to have the same ratio to average risk as tile with the average RCC risk calculated by using a Jeffreys prior Bayesian updated with 1 in 113

# ORBITER LOWER SURFACE DAMAGES ARRANGED BY ET START DATE




- Prior to ET-88 (STS-86) the average number of hits to the lower surface >1 inch was ~13, from ET-88 to ET-100 (STS-96) the average is ~45. Once the ET is vent the averages drops back down to ~16.
- ***There does not appear to be a significant difference between LWT and SLWT with regard to lower surface damages***
  - Graph starts at ET-62 because ET start date was unavailable prior to ET-62, however damage trend is similar prior to ET-62 and post return to flight after *Challenger* (with the exception of STS-27 which had significant damage due to SRB nose cap TPS debris)

# ORBITER LOWER SURFACE DAMAGES ARRANGED BY ET NUMBER




- Ordering by ET number starting with ET-27 shows a similar trend to the previous chart with no apparent significant difference between LWT and SLWT with regard to lower surface damages

# STS-1 ORBITER HARDWARE/SOFTWARE RESULTS (5th 1:120, Mean 1:69, 95th 1:42)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description |
|---|---|---|---|---|
| 1 | 3.7 | 3.7 | 3.1E-03 (1:320) | Orbiter APU Shaft Seal Fracture Entry and ejection seats fail to save the crew |
| 2 | 2.9 | 6.6 | 2.4E-03 (1:380) | Auxiliary Power Unit (APU) external leak on entry and ejection seats fail to save the crew |
| 3 | 2.0 | 8.6 | 1.7E-03 (1:600) | Orbiter flight software error results in catastrophic failure during ascent |
| 4 | 1.1 | 9.7 | 9.0E-04 (1:1100) | APU external leak on ascent |
| 5 | 1.1 | 10.8 | 8.8E-04 (1:1100) | Orbiter APU Shaft Seal Fracture Ascent |
| 6 | 0.6 | 11.4 | 4.7E-04 (1:2100) | Fuel supply failure to the OMS during orbit and crew rescue fails |
| 7 | 0.5 | 11.9 | 4.1E-04 (1:2400) | Orbiter flight software error results in catastrophic failure during entry |
| 8 | 0.4 | 12.3 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 9 | 0.4 | 12.7 | 3.6E-04 (1:2800) | Common cause failure of the Data Processing System (DPS) on orbit |
| 10 | 0.3 | 13.0 | 2.9E-04 (1:3500) | Control or mechanical failure causes Main Propulsion System (MPS) prevalves to fail to close |

# STS-5 ORBITER HARDWARE/SOFTWARE RESULTS
# (5th 1:120, Mean 1:76, 95th 1:42)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description |
|---|---|---|---|---|
| 1 | 2.5 | 2.5 | 2.6E-03 (1:380) | Auxiliary Power Unit (APU) external leak on entry |
| 2 | 1.7 | 4.2 | 1.8E-03 (1:560) | Orbiter flight software error results in catastrophic failure during ascent |
| 3 | 1.6 | 5.8 | 1.7E-03 (1:590) | Orbiter APU Shaft Seal Fracture Entry |
| 4 | 0.9 | 6.7 | 9.8E-04 (1:1000) | APU external leak on ascent |
| 5 | 0.5 | 7.2 | 4.8E-04 (1:2100) | Orbiter APU Shaft Seal Fracture Ascent |
| 6 | 0.5 | 7.7 | 4.7E-04 (1:2100) | Fuel supply failure to the OMS during orbit |
| 7 | 0.4 | 8.1 | 4.5E-04 (1:2200) | Orbiter flight software error results in catastrophic failure during entry |
| 8 | 0.4 | 8.5 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 9 | 0.3 | 8.8 | 3.6E-04 (1:2800) | Common cause failure of the Data Processing System (DPS) on orbit |
| 10 | 0.3 | 9.1 | 2.9E-04 (1:3500) | Control or mechanical failure causes Main Propulsion System (MPS) prevalves to fail to close |

# STS-41B ORBITER HARDWARE/SOFTWARE RESULTS
# (5th 1:180, Mean 1:110, 95th 1:67)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description |
|---|---|---|---|---|
| 1 | 1.7 | 1.7 | 1.7E-03 (1:590) | Orbiter APU Shaft Seal Fracture Entry |
| 2 | 1.6 | 3.3 | 1.7E-03 (1:600) | Orbiter flight software error results in catastrophic failure during ascent |
| 3 | 0.5 | 3.8 | 4.8E-04 (1:2100) | Orbiter APU Shaft Seal Fracture Ascent |
| 4 | 0.5 | 4.3 | 4.7E-04 (1:2100) | Fuel supply failure to the OMS during orbit |
| 5 | 0.4 | 4.7 | 4.2E-04 (1:2400) | Orbiter flight software error results in catastrophic failure during entry |
| 6 | 0.4 | 5.1 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 7 | 0.2 | 5.3 | 1.9E-04 (1:5200) | Common cause failure of the Data Processing System (DPS) on orbit |
| 8 | 0.2 | 5.5 | 1.9E-04 (1:5300) | Mechanisms failure |
| 9 | 0.2 | 5.7 | 1.8E-04 (1:5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling |
| 10 | 0.2 | 5.9 | 1.7E-04 (1:6000) | Flight Software error result in catastrophic failure during orbit |

# STS-51L ORBITER HARDWARE/SOFTWARE RESULTS (5th 1:240, Mean 1:160, 95th 1:110)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description |
|---|---|---|---|---|
| 1 | 1.1 | 1.1 | 1.1E-03 (1:950) | Orbiter flight software error results in catastrophic failure during ascent |
| 2 | 0.5 | 1.6 | 4.7E-04 (1:2100) | Fuel supply failure to the OMS during orbit |
| 3 | 0.4 | 2.0 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 4 | 0.3 | 2.3 | 3.4E-04 (1:2900) | Orbiter APU Shaft Seal Fracture Entry |
| 5 | 0.3 | 2.6 | 2.6E-04 (1:3800) | Orbiter flight software error results in catastrophic failure during entry |
| 6 | 0.2 | 2.8 | 1.9E-04 (1:5200) | Common cause failure of the Data Processing System (DPS) on orbit |
| 7 | 0.2 | 3.0 | 1.8E-04 (1:5500) | Mechanisms failure |
| 8 | 0.2 | 3.2 | 1.8E-04 (1:5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling |
| 9 | 0.2 | 3.4 | 1.6E-04 (1:6300) | Flight control surface (elevons, rudder, body flap) actuators fail/jam during entry |
| 10 | 0.1 | 3.5 | 1.4E-04 (1:6900) | Common cause failure of the APU System on entry |

# STS-26 ORBITER HARDWARE/SOFTWARE RESULTS (5th 1:250, Mean 1:170, 95th 1:110)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description |
|---|---|---|---|---|
| 1 | 1.3 | 1.3 | 7.5E-04 (1:1300) | Orbiter flight software error results in catastrophic failure during ascent |
| 2 | 0.8 | 2.1 | 4.7E-04 (1:2100) | Fuel supply failure to the OMS during orbit and crew rescue fails |
| 3 | 0.6 | 2.7 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 4 | 0.6 | 3.3 | 3.4E-04 (1:2900) | Orbiter APU Shaft Seal Fracture Entry |
| 5 | 0.3 | 3.6 | 1.9E-04 (1:5200) | Common cause failure of the Data Processing System (DPS) on orbit |
| 6 | 0.3 | 3.9 | 1.9E-04 (1:5300) | Orbiter flight software error results in catastrophic failure during entry |
| 7 | 0.3 | 4.2 | 1.8E-04 (1:5500) | Mechanisms failure and subsequent failure of a crew rescue attempt |
| 8 | 0.3 | 4.5 | 1.8E-04 (1:5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling |
| 9 | 0.3 | 4.8 | 1.6E-04 (1:6300) | Flight control surface (elevons, rudder, body flap) actuators fail/jam during entry |
| 10 | 0.2 | 5.0 | 1.4E-04 (1:6900) | Common cause failure of the APU System on entry |

# STS-29 ORBITER HARDWARE/SOFTWARE RESULTS (5th 1:270, Mean 1:180, 95th 1:120)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description |
|---|---|---|---|---|
| 1 | 2.7 | 2.7 | 7.6E-04 (1:1300) | Orbiter flight software error results in catastrophic failure during ascent |
| 2 | 1.6 | 4.3 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit and crew rescue fails |
| 3 | 1.3 | 5.6 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 4 | 1.2 | 6.8 | 3.4E-04 (1:2900) | Orbiter APU Shaft Seal Fracture Entry |
| 5 | 0.7 | 7.5 | 1.9E-04 (1:5200) | Common cause failure of the Data Processing System (DPS) on orbit |
| 6 | 0.7 | 8.2 | 1.9E-04 (1:5300) | Orbiter flight software error results in catastrophic failure during entry |
| 7 | 0.7 | 8.9 | 1.8E-04 (1:5500) | Mechanisms failure and subsequent failure of a crew rescue attempt |
| 8 | 0.6 | 9.5 | 1.8E-04 (1:5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling |
| 9 | 0.6 | 10.1 | 1.6E-04 (1:6300) | Flight control surface (elevons, rudder, body flap) actuators fail/jam during entry |
| 10 | 0.5 | 10.6 | 1.4E-04 (1:6900) | Common cause failure of the APU System on entry |

# STS-49 ORBITER HARDWARE/SOFTWARE RESULTS (5th 1:320, Mean 1:210, 95th 1:140)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description |
|---|---|---|---|---|
| 1 | 1.8 | 1.8 | 5.0E-04 (1:2000) | Orbiter flight software error results in catastrophic failure during ascent |
| 2 | 1.6 | 3.4 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit and crew rescue fails |
| 3 | 1.3 | 4.7 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 4 | 0.7 | 5.4 | 1.8E-04 (1:5500) | Mechanisms failure and subsequent failure of a crew rescue attempt |
| 5 | 0.6 | 6.0 | 1.8E-04 (1:5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling |
| 6 | 0.6 | 6.6 | 1.6E-04 (1:6300) | Flight control surface (elevons, rudder, body flap) actuators fail/jam during entry |
| 7 | 0.6 | 7.2 | 1.6E-04 (1:6300) | Common cause failure of the Data Processing System (DPS) on orbit |
| 8 | 0.5 | 7.7 | 1.4E-04 (1:6900) | Common cause failure of the APU System on entry |
| 9 | 0.5 | 8.2 | 1.3E-04 (1:7400) | Auxiliary Power Unit (APU) external leak on entry |
| 10 | 0.5 | 8.7 | 1.3E-04 (1:7600) | Flow Control Valve (FCV) poppet failure causes rupture in the GH2 re-pressurization line |

# STS-77 ORBITER HARDWARE/SOFTWARE RESULTS (5th 1:330, Mean 1:220, 95th 1:140)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description |
|---|---|---|---|---|
| 1 | 1.7 | 1.7 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit and crew rescue fails |
| 2 | 1.5 | 3.2 | 3.8E-04 (1:2600) | Orbiter flight software error results in catastrophic failure during ascent |
| 3 | 1.4 | 4.6 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 4 | 0.7 | 5.3 | 1.8E-04 (1:5500) | Mechanisms failure and subsequent failure of a crew rescue attempt |
| 5 | 0.7 | 6.0 | 1.8E-04 (1:5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling |
| 6 | 0.6 | 6.6 | 1.6E-04 (1:6300) | Flight control surface (elevons, rudder, body flap) actuators fail/jam during entry |
| 7 | 0.6 | 7.2 | 1.6E-04 (1:6300) | Common cause failure of the Data Processing System (DPS) on orbit |
| 8 | 0.5 | 7.7 | 1.3E-04 (1:7400) | Auxiliary Power Unit (APU) external leak on entry |
| 9 | 0.5 | 8.2 | 1.3E-04 (1:7600) | Flow Control Valve (FCV) poppet failure causes rupture in the GH2 re-pressurization line |
| 10 | 0.5 | 8.7 | 1.3E-04 (1:7600) | RCS thruster fail leak or off on orbit |

# STS-86 ORBITER HARDWARE/SOFTWARE RESULTS (5th 1:350, Mean 1:230, 95th 1:150)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description |
|---|---|---|---|---|
| 1 | 0.9 | 0.9 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit and crew rescue fails |
| 2 | 0.8 | 1.7 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 3 | 0.7 | 2.4 | 3.2E-04 (1:3100) | Orbiter flight software error results in catastrophic failure during ascent |
| 4 | 0.4 | 2.8 | 1.8E-04 (1:5500) | Mechanisms failure and subsequent failure of a crew rescue attempt |
| 5 | 0.4 | 3.2 | 1.8E-04 (1:5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling |
| 6 | 0.3 | 3.5 | 1.6E-04 (1:6300) | Flight control surface (elevons, rudder, body flap) actuators fail/jam during entry |
| 7 | 0.3 | 3.8 | 1.6E-04 (1:6300) | Common cause failure of the Data Processing System (DPS) on orbit |
| 8 | 0.3 | 4.1 | 1.3E-04 (1:7400) | Auxiliary Power Unit (APU) external leak on entry |
| 9 | 0.3 | 4.4 | 1.3E-04 (1:7600) | Flow Control Valve (FCV) poppet failure causes rupture in the GH2 re-pressurization line |
| 10 | 0.2 | 4.6 | 1.1E-04 (1:8900) | Common cause failure of the APU System on entry |

# STS-89 ORBITER HARDWARE/SOFTWARE RESULTS (5th 1:370, Mean 1:240, 95th 1:150)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description |
|---|---|---|---|---|
| 1 | 1.0 | 1.0 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit and crew rescue fails |
| 2 | 0.8 | 1.8 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 3 | 0.7 | 2.5 | 3.2E-04 (1:3100) | Orbiter flight software error results in catastrophic failure during ascent |
| 4 | 0.4 | 2.9 | 1.8E-04 (1:5500) | Mechanisms failure and subsequent failure of a crew rescue attempt |
| 5 | 0.4 | 3.3 | 1.8E-04 (1:5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling |
| 6 | 0.3 | 3.6 | 1.6E-04 (1:6300) | Flight control surface (elevons, rudder, body flap) actuators fail/jam during entry |
| 7 | 0.3 | 3.9 | 1.6E-04 (1:6300) | Common cause failure of the Data Processing System (DPS) on orbit |
| 8 | 0.3 | 4.2 | 1.3E-04 (1:7400) | Auxiliary Power Unit (APU) external leak on entry |
| 9 | 0.3 | 4.5 | 1.3E-04 (1:7600) | Flow Control Valve (FCV) poppet failure causes rupture in the GH2 re-pressurization line |
| 10 | 0.2 | 4.7 | 1.1E-04 (1:8900) | Common cause failure of the APU System on entry |

# STS-103 ORBITER HARDWARE/SOFTWARE RESULTS (5th 1:380, Mean 1:250, 95th 1:160)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description |
|---|---|---|---|---|
| 1 | 2.1 | 2.1 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit and crew rescue fails |
| 2 | 1.7 | 3.8 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 3 | 1.4 | 5.2 | 3.0E-04 (1:3400) | Orbiter flight software error results in catastrophic failure during ascent |
| 4 | 0.9 | 6.1 | 1.8E-04 (1:5500) | Mechanisms failure and subsequent failure of a crew rescue attempt |
| 5 | 0.8 | 6.9 | 1.8E-04 (1:5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling |
| 6 | 0.7 | 7.6 | 1.6E-04 (1:6300) | Common cause failure of the Data Processing System (DPS) on orbit |
| 7 | 0.7 | 8.3 | 1.5E-04 (1:6800) | Flight control surface (elevons, rudder, body flap) actuators fail/jam during entry |
| 8 | 0.6 | 8.9 | 1.3E-04 (1:7400) | Auxiliary Power Unit (APU) external leak on entry |
| 9 | 0.6 | 9.5 | 1.3E-04 (1:7600) | Flow Control Valve (FCV) poppet failure causes rupture in the GH2 re-pressurization line |
| 10 | 0.5 | 10.0 | 1.1E-04 (1:8900) | Common cause failure of the APU System on entry |

# STS-110 ORBITER HARDWARE/SOFTWARE RESULTS (5th 1:400, Mean 1:250, 95th 1:160)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description |
|---|---|---|---|---|
| 1 | 2.1 | 2.1 | 4.5E-04 (1:2200) | Fuel supply failure to the OMS during orbit |
| 2 | 1.7 | 3.8 | 3.7E-04 (1:2700) | Debonding of TPS during ascent |
| 3 | 1.2 | 5.0 | 2.6E-04 (1:3800) | Orbiter flight software error results in catastrophic failure during ascent |
| 4 | 0.9 | 5.9 | 1.8E-04 (1:5500) | Mechanisms failure |
| 5 | 0.8 | 6.7 | 1.8E-04 (1:5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling |
| 6 | 0.7 | 7.4 | 1.6E-04 (1:6300) | Common cause failure of the Data Processing System (DPS) on orbit |
| 7 | 0.6 | 8.0 | 1.3E-04 (1:7600) | Flow Control Valve (FCV) poppet failure causes rupture in the GH2 re-pressurization line |
| 8 | 0.6 | 8.6 | 1.3E-04 (1:7900) | Auxiliary Power Unit (APU) external leak on entry |
| 9 | 0.6 | 9.2 | 1.2E-04 (1:8300) | Flight control surface (elevons, rudder, body flap) actuators fail/jam during entry |
| 10 | 0.5 | 9.7 | 1.1E-04 (1:8900) | Common cause failure of the APU System on entry |

# STS-114 ORBITER HARDWARE/SOFTWARE RESULTS (5th 1:520, Mean 1:350, 95th 1:240)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description |
|---|---|---|---|---|
| 1 | 1.6 | 1.6 | 2.3E-04 (1:4400) | Orbiter flight software error results in catastrophic failure during ascent |
| 2 | 1.3 | 2.9 | 1.8E-04 (1:5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling |
| 3 | 1.0 | 3.9 | 1.3E-04 (1:7600) | Flow Control Valve (FCV) poppet failure causes rupture in the GH2 re-pressurization line |
| 4 | 0.9 | 4.8 | 1.3E-04 (1:7900) | Auxiliary Power Unit (APU) external leak on entry |
| 5 | 0.8 | 5.6 | 1.1E-04 (1:8900) | Common cause failure of the APU System on entry |
| 6 | 0.8 | 6.4 | 1.1E-04 (1:8900) | Reaction Control System (RCS) thrusters burnthrough on orbit |
| 7 | 0.7 | 7.1 | 1.0E-04 (1:9700) | Power Reactant Storage and Distribution (PRSD) tank rupture |
| 8 | 0.7 | 7.8 | 9.4E-05 (1:11000) | Common cause failure of the Electrical Power System (EPS) on orbit |
| 9 | 0.7 | 8.5 | 9.3E-05 (1:11000) | Flight control surface (elevons, rudder, body flap) actuators fail/jam during entry |
| 10 | 0.7 | 9.2 | 9.2E-05 (1:11000) | Debonding of TPS during ascent |

# STS-133 ORBITER HARDWARE/SOFTWARE RESULTS (5th 1:550, Mean 1:370, 95th 1:250)

| Rank | % of Total | Cumulative Total | Probability (1/n) | Description |
|---|---|---|---|---|
| 1 | 2.0 | 2.0 | 2.3E-04 (1 :4400) | Orbiter Flight Software error result in catastrophic failure during ascent |
| 2 | 1.6 | 3.6 | 1.8E-04 (1 :5600) | Ammonia Boiler System (ABS) isolation valve leaks on Orbit overcooling the H20 loops and crew is unable to prevent rupture of the interchanger resulting in Loss of All Cooling |
| 3 | 1.2 | 4.8 | 1.3E-04 (1 :7600) | Flow Control Valve (FCV) poppet failure causes rupture in the GH2 re-pressurization line |
| 4 | 1.1 | 5.9 | 1.3E-04 (1 :7900) | Auxiliary Power Unit (APU) external leak on entry |
| 5 | 1.0 | 6.9 | 1.1E-04 (1:8900) | Reaction Control System (RCS) thrusters burnthrough on orbit |
| 6 | 0.9 | 7.8 | 1.0E-04 (1:9700) | Power Reactant Storage and Distribution (PRSD) tank rupture |
| 7 | 0.8 | 8.6 | 9.4E-05 (1:11000) | Common cause failure of the Electrical Power System (EPS) on orbit |
| 8 | 0.8 | 9.4 | 9.3E-05 (1:11000) | Flight control surface (elevons, rudder, body flap) actuators fail/jam during entry |
| 9 | 0.8 | 10.2 | 9.1E-05 (1:11000) | Common cause failure of the APU System on entry |
| 10 | 0.8 | 11.0 | 8.4E-05 (1:12000) | Control or mechanical failure causes Main Propulsion System (MPS) prevalves to fail to close |

# EXAMPLES FUNCTIONAL DATA CHANGES

| Index | STS-1 | STS-51L | STS-26 | STS-49 | STS-110 | STS-114 | STS-121 | Iter 3.2 | |
|---|---|---|---|---|---|---|---|---|---|
| act_120a | 8.75E-06: Power Spool that Sums (combines) hydraulic force from individual systems/control valves to drive the Primary Actuator, jams | 8.75E-06 | 8.75E-06 | 8.75E-06 | ... | ... | ... | 2.81E-06 | Bayesian. Credit for design change beginning STS-101 |
| act_320j | 7.77E-06: The Hydraulic Ram - muscle - that moves the Elevons, SSME TVC pitch & yaw, & Landing Gear | 7.77E-06 | 7.77E-06 | 7.77E-06 | ... | ... | ... | 5.50E-06 | Bayesian. Credit for added test beginning STS-91 |
| apu_284a | 2.13E-03: MPU fails low | 2.13E-03 | 2.13E-03 | 2.13E-03 | ... | ... | ... | 4.86E-04 | Bayesian. Credit for manufacturing, design and vander change beginning STS-82 |
| apu-289a | 1.41E-03: APU fails to start | 1.41E-03 | 1.41E-03 | 1.41E-03 | 1.41E-03 | 1.41E-03 | 1.41E-03 | 6.60E-04 | Bayesian. Heater added to GN2 QD beginning STS-124 |
| apu_314a | 4.36E-03: APU Fails to Run | 3.49E-03 | 3.49E-03 | 3.49E-03 | ... | ... | ... | 1.76E-03 | Bayesian. Credit for clean room procedures beginning STS-80 |
| duct_110x | 1.27E-03: IAPU Exhaust Leak Repurposed to APU Shaft Seal failure prior to IAPU | 1.27E-04 | 1.27E-04 | ... | ... | ... | ... | 1.95E-06 | IAPU exhaust leak prior to STS-47 was repurposed. APU Shaft Seal failure with process improvements following STS-9, and redesigned injector tube beginning STS 61-C. |
| atcs-441 | 5.93E-03: Icicle Forms from Water Dump Nozzle redesigned after 2ft icicle forms durring STS 41-D | ... | ... | ... | ... | ... | ... | 2.37E-03 | Water dump nozzle redesigned after STS 41-D (2ft icicle) |
| eco-wet | 4.14E-03: Engine Cut-Off sensor fails Wet Source does not include 1st 6 flights due to redesign of sensor wiring. | ... | ... | ... | ... | ... | ... | 4.14E-04 | ECO sensor wiring redesigned beginning STS-7 |
| flt_100r | 2.90E-05: OMS Engine Restricted flow | ... | ... | ... | ... | ... | ... | 1.56E-05 | Bayesian. Contamination on STS-1. |
| flt_110f | 4.38E-07: FCL filter plugged | 4.38E-07 | 4.38E-07 | 3.82E-07 | ... | ... | ... | 2.16E-07 | Bayesian. Anti-contamination procedures and design changes beginning STS-41. Braze procedure changes beginning STS-110 |
| eps-7e | 2.78E-05: Fuel cell fails to run (produce power) | 2.78E-05 | 2.78E-05 | 2.78E-05 | ... | ... | ... | 2.22E-05 | Bayesian. Instrumentation added to provide insight beginning STS-84 |

Note: … means it is equal to SPRA iteration 3.3

# EXAMPLES FUNCTIONAL DATA CHANGES (2)

| Index | STS-1 | STS-51L | STS-26 | STS-49 | STS-110 | STS-114 | STS-121 | Iter 3.2 | |
|---|---|---|---|---|---|---|---|---|---|
| eps-8e | 8.64E-06: Phenomenlogical failure of fuel cell | 8.64E-06: | ... | ... | ... | ... | ... | 7.56E-06 | Bayesian. Changes in design beginning STS-26 |
| gbx_110a | 6.58E-06: Rotary Actuator Jams | 6.58E-06: | 6.58E-06 | 6.58E-06: | 6.58E-06: | ... | ... | 3.70E-06 | Bayesian. Corrective action taken after gears found to be installed reversed beginning STS-114 |
| gyro_103r | 6.46E-06: Loss of Output from Orbiter Rate Gyro Assy | 6.46E-06: | 6.46E-06 | ... | ... | ... | ... | 9.86E-07 | Bayesian. Design change beginning STS-32 |
| gyro_105b | 7.09E-06: Loss of Output from Inertial Measurement Unit (IMU) (3 Gyros + 2 Accelerometers) | 7.09E-06: | 7.09E-06 | 7.09E-06: | 5.73E-06: | ... | ... | 4.97E-06 | Bayesian. Design and manufacturing changes beginning STS-109 |
| htr_140a | 3.20E-05: Electrical resistance heater. APU heater fails on. | 3.20E-05: | 3.20E-05 | ... | ... | ... | ... | 1.69E-05 | Bayesian. Design changes beginning STS-41 |
| lds_826 | 2.20E-06: Failure of 1 of 4 MLG tires due to FOD Prior to STS 51-L 54% landings at lakebed vs 7% afterward | 2.20E-06: | ... | ... | ... | ... | ... | 2.20E-07 | Lakebed landings reduced from 54% to 7% beginning STS-26 |
| lgr-035 | 1.00E-04: Lockup of 1 of 4 brakes due to structural failure Brake material changed from Beryllium to Carbon beginning with STS-31 | 1.00E-04: | 1.00E-04 | ... | ... | ... | ... | 1.00E-05 | Brake material changed from Beryllium to Carbon beginning with STS-31 |
| lds-371 | 0.00E00: Drag chute door opens prematurely No drag chute prior to STS-49 | 0.00E00: | 0.00E00: | 2.17E-02: | ... | ... | ... | 1.49E-03 | No drag chute prior to STS-49. Door pin changed from Aluminum to Inconnel after STS-95 |
| lds-372 | 0.00E00: Drag chute door opens prematurely No drag chute prior to STS-49 | 0.00E00: | 0.00E00: | 1.11E-02: | ... | ... | ... | 7.58E-04 | No drag chute prior to STS-49. Door pin changed from Aluminum to Inconnel after STS-95 |
| lds-381 | 0.00E00: Cond prob drag chute door failure leads to LOCV No drag chute prior to STS-49 | 0.00E00: | 0.00E00: | ... | ... | ... | ... | 1.78E-03 | No drag chute prior to STS-49 |
| lds-382 | 0.00E00: Cond prob drag chute door failure leads to LOCV No drag chute prior to STS-49 | 0.00E00: | 0.00E00: | ... | ... | ... | ... | 1.33E-03 | No drag chute prior to STS-49 |

Note: … means it is equal to SPRA iteration 3.3

# EXAMPLES FUNCTIONAL DATA CHANGES (3)

| Index | STS-1 | STS-51L | STS-26 | STS-49 | STS-110 | STS-114 | STS-121 | Iter 3.2 | |
|---|---|---|---|---|---|---|---|---|---|
| mech-800 | 8.91E-06: Electromechanical actuator fails to actuate | 7.77E-06: | 7.77E-06 | 7.77E-06: | 7.77E-06: | ... | ... | 5.59E-06 | Bayesian. Vender and procedure changes beginning STS 41-B. Procedure changes beginning STS 51-G. Design and procedure changes beginning STS-114 |
| mdm_101 | 4.66E-05: Surrogate mean based on All failures for 5xxx type card, the predominant type in service STS-1 thru STS-9 | ... | ... | ... | ... | ... | ... | 1.48E-05 | 6xxx series MDM becomes dominant beginning STS 41-B |
| mdm_101 | 6.87E-06: General Purpose Computer fails. Based on All failures for 6xxx MDM | 6.69E-06: | 6.69E-06 | ... | ... | ... | ... | 1.89E-06 | Bayesian. Prior based on 5xxx series MDM before STS 41-B. Updated GPC design beginning STS-43 |
| mdm_110 | 2.91E-06: DPS MDM MIA Fails, from MDM report 2007 Adjusted for 5xxx, STS-1 thru STS-9 | ... | ... | ... | ... | ... | ... | 9.26E-07 | 6xxx series MDM becomes dominant beginning STS 41-B |
| mdm_111 | 2.91E-06: Surrogate mean based on DPS MDM MIA Fails, from MDM report 2007 Adjusted for 5xxx, STS-1 thru STS-9 | ... | ... | ... | ... | ... | ... | 9.26E-07 | 6xxx series MDM becomes dominant beginning STS 41-B |
| mdm_111 | 2.30E-07: Backup Flight Controller fails. Based on All failures for 6xxx MDM | ... | ... | ... | ... | ... | ... | 1.96E-07 | 6xxx series MDM becomes dominant beginning STS 41-B |
| mdm_120 | 5.51E-06: DPS MDM Input/Output Module Fails, from MDM report 2007 Adjusted for 5xxx, STS-1 thru STS-9 | ... | ... | ... | ... | ... | ... | 1.76E-06 | 6xxx series MDM becomes dominant beginning STS 41-B |
| mdm_121 | 5.51E-06: Surrogate mean based on DPS MDM Input/Output Module Fails, from MDM report 2007 Adjusted for 5xxx, STS-1 thru STS-9 | ... | ... | ... | ... | ... | ... | 1.76E-06 | 6xxx series MDM becomes dominant beginning STS 41-B |
| mdm_121 | 1.10E-05: DPS Pulse Code Master Modulator Unit Fails. Based on IOM from MDM report 2007 | ... | ... | ... | ... | ... | ... | 9.70E-06 | 6xxx series MDM becomes dominant beginning STS 41-B |
| mdm_121 | 5.08E-06: Flight control channel fails. Based on IOM from MDM report 2007 | ... | ... | ... | ... | ... | ... | 4.72E-06 | 6xxx series MDM becomes dominant beginning STS 41-B |
| mdm_130 | 1.09E-05: DPS MDM SCU Fails, from MDM report 2007 Adjusted for 5xxx, STS-1 thru STS-9 | ... | ... | ... | ... | ... | ... | 3.47E-06 | 6xxx series MDM becomes dominant beginning STS 41-B |

Note: … means it is equal to SPRA iteration 3.3

# EXAMPLES FUNCTIONAL DATA CHANGES (4)

| Index | STS-1 | STS-51L | STS-26 | STS-49 | STS-110 | STS-114 | STS-121 | Iter 3.2 | |
|---|---|---|---|---|---|---|---|---|---|
| mdm_140 | 9.45E-06: DPS MDM Power Supply Fails, from MDM report 2007 Adjusted for 5xxx, STS-1 thru STS-9 | ... | ... | ... | ... | ... | ... | 3.01E-06 | 6xxx series MDM becomes dominant beginning STS 41-B |
| mdm_141 | 9.45E-06: Surrogate mean based on DPS MDM Power Supply Fails, from MDM report 2007 Adjusted for 5xxx, STS-1 thru STS-9 | ... | ... | ... | ... | ... | ... | 3.01E-06 | 6xxx series MDM becomes dominant beginning STS 41-B |
| mdm_141 | 3.75E-05: Flight control ASA, ATVC Box fails | ... | ... | ... | ... | ... | ... | 2.96E-05 | 6xxx series MDM becomes dominant beginning STS 41-B |
| pip_210h | 1.91E-06: Hydraulic Flex Hose Leak | 1.91E-06: | 1.91E-06 | 1.91E-06: | ... | ... | ... | 1.11E-06 | Bayesian. Procedure changes beginning STS-77 |
| pmp_100h | 1.28E-03: Main Hydraulic Pump, fails to start Solenoid controlled swash plate jams | 1.28E-03: | 1.28E-03 | 1.28E-03: | ... | ... | ... | 8.27E-04 | Bayesian. Design changes beginning STS-73 |
| rad-100 | 1.12E-03: Microwave Reciever Transmitter: TACAN Tactical Air Nav Gould TACAN for STS-1 thru STS-45 | 1.12E-03: | 1.12E-03 | ... | ... | ... | ... | 2.63E-04 | Gould TACAN for STS-1 thru STS-45 |
| reg_110r | 6.00E-06: Gas regulator, fails closed | 6.00E-06: | 6.00E-06 | ... | ... | ... | ... | 1.67E-06 | Bayesian. Design and maintenance changes beginning STS-27. Production process changed starting STS-28 |
| reg_120m | 7.23E-05: Gas regulator, fails open (High) | 7.23E-05: | 5.23E-05 | ... | ... | ... | ... | 4.11E-05 | Bayesian. Bellows redesign beginning STS-26. Brazing process changed starting STS-28 |
| rcs-230 | 8.10E-03: RCS primary thruster, fails to fire | 8.10E-03: | 8.10E-03 | 8.10E-03: | 4.36E-03: | ... | ... | 3.38E-03 | Bayesian. Nitrate contamination flushing beginning STS-78. Teflon extrusion procedures beginning STS-114 |
| rcs-243 | 1.50E-05: RCS primary thruster, leaks | 1.50E-05: | 1.50E-05 | 1.50E-05: | ... | ... | ... | 6.90E-06 | Bayesian. Nitrate contamination flushing beginning STS-78 |
| RSRMCAT | 2.00E-02: RSRM Catastrophic Failure (Mainstage) STS-1 thru STS 51L (demonstrated) | 2.00E-02: | ... | ... | ... | ... | ... | 3.27E-04 | RSRM redesigned beginning STS-26 |

Note: … means it is equal to SPRA iteration 3.3

# EXAMPLES FUNCTIONAL DATA CHANGES (5)

| Index | STS-1 | STS-51L | STS-26 | STS-49 | STS-110 | STS-114 | STS-121 | Iter 3.2 | |
|---|---|---|---|---|---|---|---|---|---|
| SRBFBSMTHRT | 4.78E-03: SRB Fwd BSM Axial Crack occurs in Graphite Throat | 4.78E-03: | 4.78E-03 | 4.78E-03 | 3.18E-03: | 3.18E-03: | 3.18E-03 | 2.39E-03 | Bayesian. Count crack in throat CAR discounted as 0.5 beginning STS-108 and as 0.25 beginning STS-122 |
| SRBLPLK | 3.18E-09: SRB APU low press hydrazine leak | 3.18E-09: | 3.18E-09 | 3.18E-09: | 3.18E-09: | 3.18E-09: | 3.18E-09 | 2.20E-10 | |
| SRBHPHDZLK | 7.26E-05: SRB APU high press hydrazine leak | 1.02E-07: | 1.02E-07 | 1.02E-07: | 1.02E-07: | 1.02E-07: | 1.02E-07 | 2.49E-08 | |
| SSMECAT | 9.65E-04: SSME Catastrophic Failure | 2.73E-03: | 1.28E-03 | 1.28E-03 | 5.57E-04: | 5.57E-04 | 5.57E-04 | 4.99E-04 | SSME estimates obtained for FMOE, FPL, (Block I/IA & Block IIA pending), Block II, and Block II w/AHMS |
| SSMECAT-A | 1.11E-03: SSME Catastrophic Failure - ATO | 3.15E-03: | 1.47E-03 | 1.47E-03 | 6.43E-04: | 6.43E-04 | 6.43E-04 | 5.75E-04 | SSME estimates obtained for FMOE, FPL, (Block I/IA & Block IIA pending), Block II, and Block II w/AHMS |
| SSMECAT-P | 9.47E-04: SSME Catastrophic Failure - PTM | 2.68E-03: | 1.25E-03 | 1.25E-03 | 5.47E-04: | 5.47E-04 | 5.47E-04 | 4.83E-04 | SSME estimates obtained for FMOE, FPL, (Block I/IA & Block IIA pending), Block II, and Block II w/AHMS |
| SSMECAT-R | 1.39E-03: SSME Catastrophic Failure - RTLS | 3.94E-03: | 1.84E-03 | 1.84E-03 | 8.04E-04: | 8.04E-04 | 8.04E-04 | 7.19E-04 | SSME estimates obtained for FMOE, FPL, (Block I/IA & Block IIA pending), Block II, and Block II w/AHMS |
| SSMECAT-T | 1.23E-03: SSME Catastrophic Failure - TAL | 3.47E-03: | 1.62E-03 | 1.62E-03 | 7.07E-04: | 7.07E-04 | 7.07E-04 | 6.33E-04 | SSME estimates obtained for FMOE, FPL, (Block I/IA & Block IIA pending), Block II, and Block II w/AHMS |
| SSMESHDN | 7.61E-03: SSME Benign Shutdown Occur | 8.67E-03: | 2.41E-03 | 2.41E-03 | 1.01E-03: | 1.01E-03 | 1.01E-03 | 1.06E-03 | SSME estimates obtained for FMOE, FPL, (Block I/IA & Block IIA pending), Block II, and Block II w/AHMS |
| SSMESHDN-A | 8.78E-03: SSME Benign Shutdown - ATO | 1.00E-02: | 2.78E-03 | 2.78E-03 | 1.16E-03: | 1.16E-03 | 1.16E-03 | 1.14E-03 | SSME estimates obtained for FMOE, FPL, (Block I/IA & Block IIA pending), Block II, and Block II w/AHMS |
| SSMESHDN-P | 7.47E-03: SSME Benign Shutdown - PTM | 8.50E-03: | 2.36E-03 | 2.36E-03 | 9.89E-04: | 9.89E-04 | 9.89E-04 | 1.04E-03 | SSME estimates obtained for FMOE, FPL, (Block I/IA & Block IIA pending), Block II, and Block II w/AHMS |

Note: … means it is equal to SPRA iteration 3.3

# EXAMPLES FUNCTIONAL DATA CHANGES (6)

| Index | STS-1 | STS-51L | STS-26 | STS-49 | STS-110 | STS-114 | STS-121 | Iter 3.2 | |
|---|---|---|---|---|---|---|---|---|---|
| SSMESHDN-R | 1.10E-02: SSME Benign Shutdown - RTLS | 1.25E-02: | 3.47E-03 | 3.47E-03: | 1.45E-03 | 1.45E-03 | 1.45E-03 | 1.27E-03 | SSME estimates obtained for FMOE, FPL, (Block I/IA & Block IIA pending), Block II, and Block II w/AHMS |
| SSMESHDN-T | 9.66E-03: SSME Benign Shutdown - TAL | 1.10E-02: | 3.06E-03 | 3.06E-03: | 1.28E-03 | 1.28E-03 | 1.28E-03 | 1.20E-03 | SSME estimates obtained for FMOE, FPL, (Block I/IA & Block IIA pending), Block II, and Block II w/AHMS |
| swf-ab | 4.32E-03: OI-01 Flight software fails on Abort | 2.52E-03 | 1.81E-03 | 1.20E-03: | 6.25E-04 | ... | ... | 5.42E-04 | Flight software changes between most flight intervals |
| swf-asc | 1.80E-03: OI-01 Flight software fails on Ascent | 1.05E-03 | 7.54E-04 | 4.99E-04: | 2.60E-04 | ... | ... | 2.26E-04 | Flight software changes between most flight intervals |
| swf-orb | 1.79E-04: OI-01Flight software fails on Orbit | 1.05E-04 | 7.53E-05 | 4.98E-05: | 2.60E-05 | ... | ... | 2.26E-05 | Flight software changes between most flight intervals |
| swf-ent | 4.48E-04: OI-01 Flight software fails on Entry | 2.62E-04 | 1.88E-04 | 1.25E-04: | 6.48E-05 | ... | ... | 5.65E-05 | Flight software changes between most flight intervals |
| cscs | 1.00E00: Crew Rescue Fails, No rescue prior to STS-114 | 1.00E00: | 1.00E00: | 1.00E00: | 1.00E00: | 2.00E-01 | ... | 1.69E-01 | No Crew Rescue prior to STS-114, 3.2 value used beginning STS-121 |
| FD2_NOSE_T | 1.00E00: Percentage of nose damage that goes undetected during FD2 inspection, N/A prior to STS-114 | 1.00E00: | 1.00E00: | 1.00E00: | 1.00E00: | 1.00E-01 | ... | 1.00E-03 | No Inspection prior to STS-114, 3.2 value used beginning STS-121 |
| RPR-NOAX | 1.00E00: TPS - NOAX Repair Fails, None prior to STS-114 | 1.00E00: | 1.00E00: | 1.00E00: | 1.00E00: | ... | ... | 1.00E-01 | No Repair prior to STS-114, 3.2 value used beginning STS-121 |
| RPR-PLUG | 1.00E00: TPS - Plug Repair Fails, None prior to STS-114 | 1.00E00: | 1.00E00: | 1.00E00: | 1.00E00: | 3.00E-01 | ... | 2.50E-01 | No Repair prior to STS-114, 3.2 value used beginning STS-121 |
| tps-lg-E | 1.00E00: TPS - Large Tile Repair Failure on Entry, None prior to STS-114 | 1.00E00: | 1.00E00: | 1.00E00: | 1.00E00: | 3.00E-01 | ... | 1.25E-01 | No Repair prior to STS-114, 3.2 value used beginning STS-121 |
| tps-lg-O | 1.00E00: TPS - Large Tile Repair Failure on Orbit, None prior to STS-114 | 1.00E00: | 1.00E00: | 1.00E00: | 1.00E00: | 5.00E-01 | ... | 5.56E-02 | No Repair prior to STS-114, 3.2 value used beginning STS-121 |
| ad-e-wash | 3.83E-03: Critical tile damage on ascent and emittance wash repair fails | 3.83E-03: | 3.83E-03 | 6.64E-05: | 6.64E-05 | 6.64E-05 | ... | 1.77E-05 | Ascent debris mitigations beginning STS-29 and STS-121 |

Note: … means it is equal to SPRA iteration 3.3

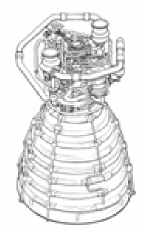
# EXAMPLES FUNCTIONAL DATA CHANGES (7)

| Index | STS-1 | STS-51L | STS-26 | STS-49 | STS-110 | STS-114 | STS-121 | Iter 3.2 | |
|---|---|---|---|---|---|---|---|---|---|
| ad-t-rad | 1.16E-02: Critical tile damage repaired requiring large area repair (t-rad or overlay) | 1.16E-02 | 1.16E-02 | 3.00E-03 | 3.00E-03 | 3.00E-03 | ... | 1.68E-03 | Ascent debris mitigations beginning STS-29 and STS-121 |
| ad-undet | 2.71E-04: Undetected critical tile damage occurs on ascent | 2.71E-04 | 2.71E-04 | 7.04E-05 | 7.04E-05 | 7.04E-05 | ... | 3.87E-05 | Ascent debris mitigations beginning STS-29 and STS-121 |
| ad-tal | 1.55E-02: Critical tile damage during TAL | 1.55E-02 | 1.55E-02 | 4.15E-03 | 4.15E-03 | 4.15E-03 | ... | 1.95E-03 | Ascent debris mitigations beginning STS-29 and STS-121 |
| ad-rcc | 4.76E-02: Three times Historical RCC damage probability (3x 1:126)<br>x2 since model will divide by two | 4.76E-02 | 4.76E-02 | 1.59E-02 | 1.59E-02 | 1.59E-02 | ... | 7.94E-03 | Ascent debris mitigations beginning STS-29 and STS-121 |
| vlp_100p | 9.19E-05: MPS Prevalve, fails to operate | ... | ... | ... | ... | ... | ... | 2.46E-05 | Bayesian. Debris screen added beginning STS-8 |
| vlr_130m | 2.09E-06: Pneumatic relief valve fails open | 2.09E-06 | 2.09E-06 | ... | ... | ... | ... | 1.92E-06 | Bayesian. Contamination procedures added beginning STS-36 |
| vls_200e | 2.63E-04: Brake Extend valve, fails to operate (LV11, LV42) | 2.63E-04 | 2.63E-04 | 2.63E-04 | ... | ... | ... | 2.04E-04 | Bayesian. Contamination prevention beginning STS-68 |

Note: … means it is equal to SPRA iteration 3.3

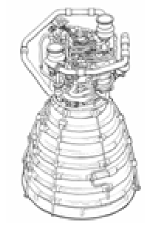
# SSME CONFIGURATIONS

## First Manned Orbital Flight



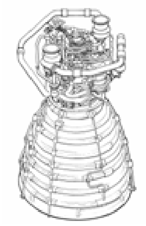
- Base Line Engine
- First Flight

## Full Power Level



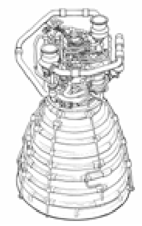
- Powerhead/ Ducts
  - HGM Fuel Bowl Liner Mods
  - Lox Post Support pins in FPB
  - New Flow Meter Straightener
  - LOX Post shields
- HPFTP
  - Kel-F Seals
  - Replaces stepped interstage seals with smooth
  - Increased clearance turbine blade clearance to tip seal
- HPOTP
  - Housing material changed (INCO 903)
- LPFTP
  - Revised blocking area
- LPOTP
  - **Turbine discharge turning vane mod**
- Avionics
- Nozzle
  - Increased tube wall thickness
  - Added steam loop
- First Flight STS-6

## Phase II Return-to-Flight



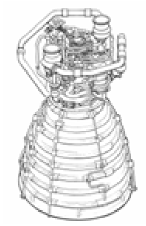
- HPFTP
  - Shot peened Fir Trees
  - Large Coolant Discharge Orifices
- HPOTP
  - Bearing Changes
  - Damping Seals
  - Two Piece Dampers
- MCC
  - EDNi Reinforced Outlet Neck
  - Burst Diaphragm Drainline
- HPF Duct He Barrier
- Avionics/Valves
  - Increased Strength MFV Housing
  - Anti-Backlash Couplings
  - Potted Wireways
  - Tight Stack GCV
  - Modified Pressure Sensor Cavity
  - Improved Hot-Gas temperature Sensor
  - Spark Igniter Case Structural Improvements
  - 4k Hz Monitor
  - Skin Temp Sensor added to Anti-flood Valve
- First Flight STS-26R

## Block I



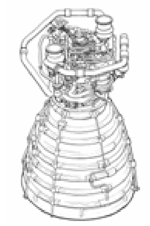
- Phase II+ Power head (Two Duct)
- Single Tube HEX
- HPOTP/AT
- Thermocouples
- First Flight STS-70

## Block IA



- Main Injector Modifications Programmed Secondary Faceplate Coolant Holes
- First Flight STS-73

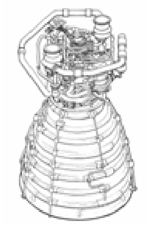
## Block IIA



- Large Throat MCC
  - Cast Inlet/Outlet Elbows
- 20 Hole Fuel Sleeves
- Block II LPOTP
- Block II LPFTP
- A-Cal Software
- Actuator Spool Material Improvement
- Filtered Check valves
- Pressure Sensor Improvements
- First Flight STS-89

- Opened BLC holes to minimize for faceplate erosion STS-96

## Block II



- HPFTP/AT
- Main Fuel Valve
- Nonintegral Spark Igniter

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